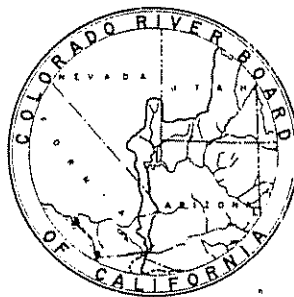


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State of California
THE RESOURCES AGENCY
Colorado River Board of California

NEED FOR
CONTROLLING SALINITY
OF THE
COLORADO RIVER



AUGUST 1970

NORMAN B. LIVERMORE, JR.
Secretary for Resources
The Resources Agency

RONALD REAGAN
Governor
State of California

MYRON B. HOLBURT
Chief Engineer
Colorado River Board

NEED FOR CONTROLLING
SALINITY
OF THE COLORADO RIVER

COLORADO RIVER BOARD
OF
CALIFORNIA
AUGUST 1970

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CHAIRMAN AND COLORADO
RIVER COMMISSIONER
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WATER DISTRICT

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SAN DIEGO COUNTY
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MYRON B. HOLBURN
CHIEF ENGINEER

August 13, 1970

Honorable Norman B. Livermore, Jr.
Secretary for Resources
The Resources Agency
1416 Ninth Street
Sacramento, California 95814

Dear Mr. Livermore:

Transmitted herewith is the report "Need for Controlling Salinity of the Colorado River," which was adopted by the Colorado River Board at its August 12, 1970, meeting.

The report presents the results of an appraisal of sources of salinity of the Colorado River, probable increases in the river's salinity that will occur in the future, deleterious impact that such increases will have on California's users of Colorado River water, possible measures for controlling the river's salinity, and recommendations for actions that, if effected, would tend to keep the river's salinity from increasing above its present high levels. We will work in concert with your office, other state agencies, and the California agencies that use Colorado River water to implement its recommendations.

In preparing this report the Board's staff worked very closely with the staffs of the Department of Water Resources and the State Water Resources Control Board. Their helpful consultations, review and comments are greatly appreciated.

Very truly yours,

RAYMOND R. RUMMONDS
Chairman and Colorado River
Commissioner

August 3, 1970

TO: Members, Colorado River Board of California

FROM: Myron B. Holburt

Gentlemen:

I am pleased to submit the report by the Board staff entitled "Need for Controlling Salinity of the Colorado River." I recommend that the Colorado River Board adopt this report and together with other state agencies and California's Colorado River water-using agencies seek implementation of its recommendations.

The report shows that, since the early 1950's, there has been a general rise in salinity of the Colorado River. At Parker Dam, the salinity now averages about 740 parts per million (ppm) of total dissolved solids, and at Imperial Dam, the salinity averages about 850 ppm with substantially higher seasonal values. If no salinity control measures are undertaken and water development projects are constructed as planned, average salinity at Parker Dam is projected to average 1110 ppm by the turn of the century. The year 2000 projection for Imperial Dam is 1340 ppm.

Salinity is a basinwide problem. Although most of the developments affecting salinity will occur in the Upper Basin, some projects planned for the Lower Basin will also cause increases in salinity at Imperial Dam. High salinity causes significant damage to the Lower Basin states of Arizona, Nevada, and California, as well as the Republic of Mexico. It is difficult to precisely determine dollar values for damages. However, in California alone it is estimated that the total cost is in the order of \$8 - \$10 million a year for each 100 ppm increase in salinity. The above figures indicate that unless salinity control measures are undertaken, annual damages in California may exceed \$40 million by the year 2000.

Federal agencies have investigated a number of salinity control projects on a reconnaissance level basis. If these projects are all constructed, they would remove 2.8 million tons of salt per year, or about 25 percent of the 11.4 million tons of salt now estimated to be reaching Hoover Dam each year after the year 2000. These salinity control projects are estimated to cost in the order of \$380,000,000, and the unit cost of salt removal would generally be in the range of \$4 to \$12 per ton of salt per year. The annual cost is in the order of \$3 for each acre-foot of mainstream water. Construction of these projects in a timely manner would reduce the projected salinity at Parker and Imperial Dams by about 25 percent.

The Federal Government bears a heavy responsibility to seek cooperative solutions with the states and concerned agencies to

Colorado River salinity problems since it has financed most of the projects that contribute to these problems, plans to finance other projects that will increase salinity in the basin, and has international obligations on the Colorado River.

The severity of the salinity problem requires that control measures be started soon to prevent the projections indicated earlier in this letter from becoming a reality.

The key policy objective should be to maintain the salinity of the Lower Colorado River at or near present levels. In order to meet this objective, construction of salinity control projects should be scheduled for completion coincident with completion of water projects that would increase salinity in the Colorado River Basin. This will require two levels of activity: (1) meetings with other Colorado River Basin states and the Federal Government for the purpose of establishing an action program to control Colorado River salinity within the framework of basinwide planning, and (2) meetings with other basin states and the Federal Government for the purpose of establishing numerical values for Colorado River salinity criteria for incorporation as part of each state's water quality standards under the Federal Water Quality acts. A legislative and financing plan needs to be developed for a Colorado River salinity control program that would provide for federal construction of salinity control projects.

Although there is no augmentation project in the planning stage at the present time, California and the other basin states should continue to work for augmentation of the Colorado River as an additional solution to the salinity problem.

The State Water Resources Control Board's briefing conference on Colorado River salinity problems in September 1969 was helpful in that it led to a memorandum of understanding concerning this report between the Colorado River Board, State Water Resources Control Board, and Department of Water Resources. We received valuable assistance and counsel during the course of these studies in preparation of the report from the staffs of the State Water Resources Control Board, Department of Water Resources, Attorney General, and the California agencies receiving water from the Colorado River. In addition, essential data was obtained through the cooperation and assistance of the Federal Water Quality Administration. This report was prepared under the general direction of the undersigned, with direct supervision provided by Vernon Valantine, Principal Hydraulic Engineer.

Myron B. Holburt
MYRON B. HOLBURT
Chief Engineer

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CHAPTER I

INTRODUCTION

The purposes of this report are to evaluate the present and future salinity of the Colorado River and to indicate ways to alleviate damaging salinity conditions. It is intended that it will generate a state policy on the pressing and complex interstate and intrastate problems relating to the river's salinity, and assist in the development of salinity control programs with the other Colorado River Basin states and federal agencies.

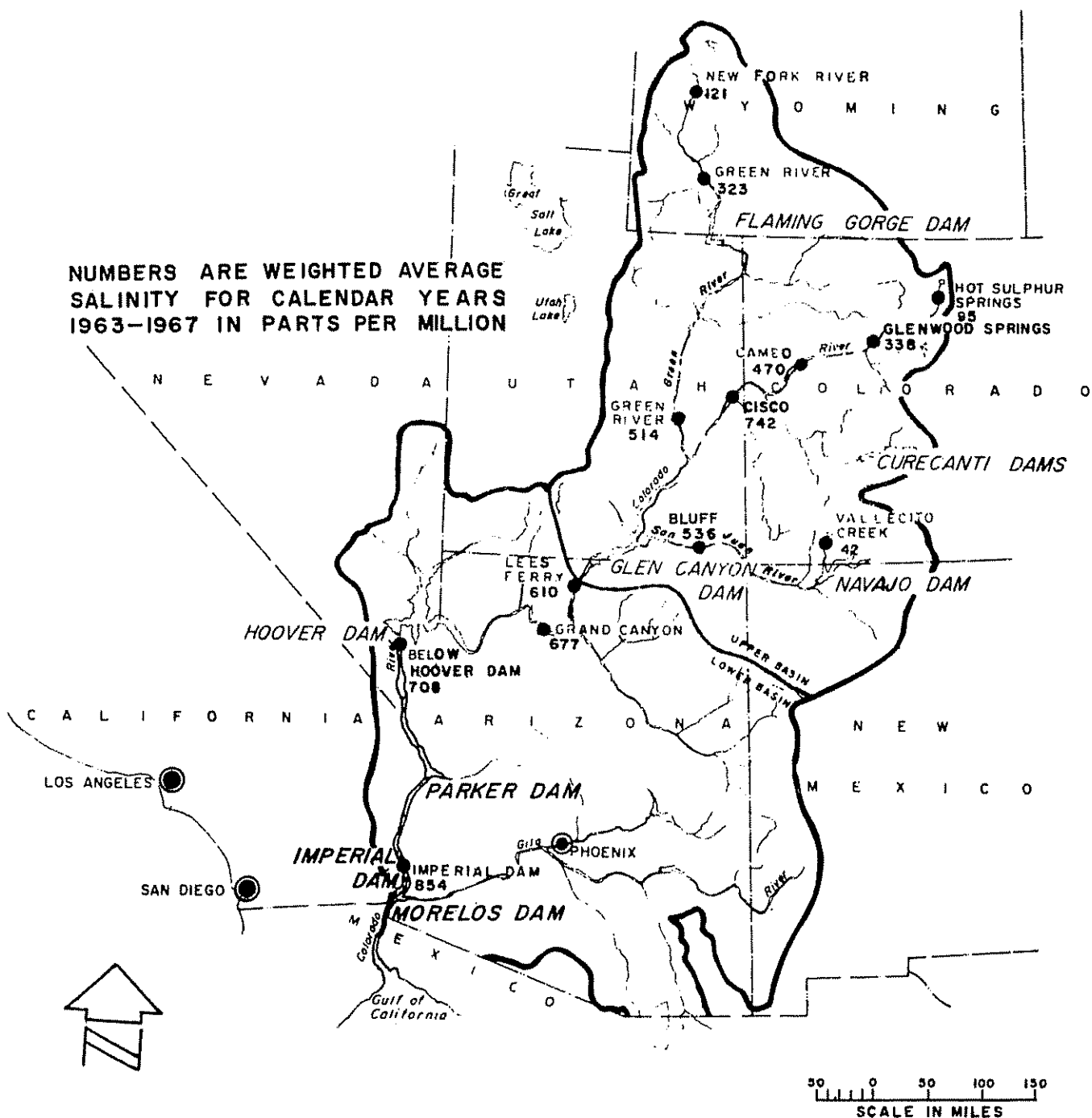
The Colorado River Basin, a 244,000 square mile area comprising portions of the seven southwestern states of the United States and of northwestern Mexico, is a significant source of water for each of the states and Mexico. The geographic area of the basin within the southwestern United States is depicted on Figure 1, "Salinity at Selected Stations Within Colorado River Basin."

At the present time, approximately 80 percent of the water consumptively used in Southern California comes from the river. This water is used for irrigation of nearly 700,000 acres in Imperial, Coachella, Palo Verde, and Yuma Valleys in California and as a supplemental supply for over 10,000,000 people in coastal Southern California. The service areas for Colorado River water in California are shown on Figure 2, "California Developments Using Colorado River Water."

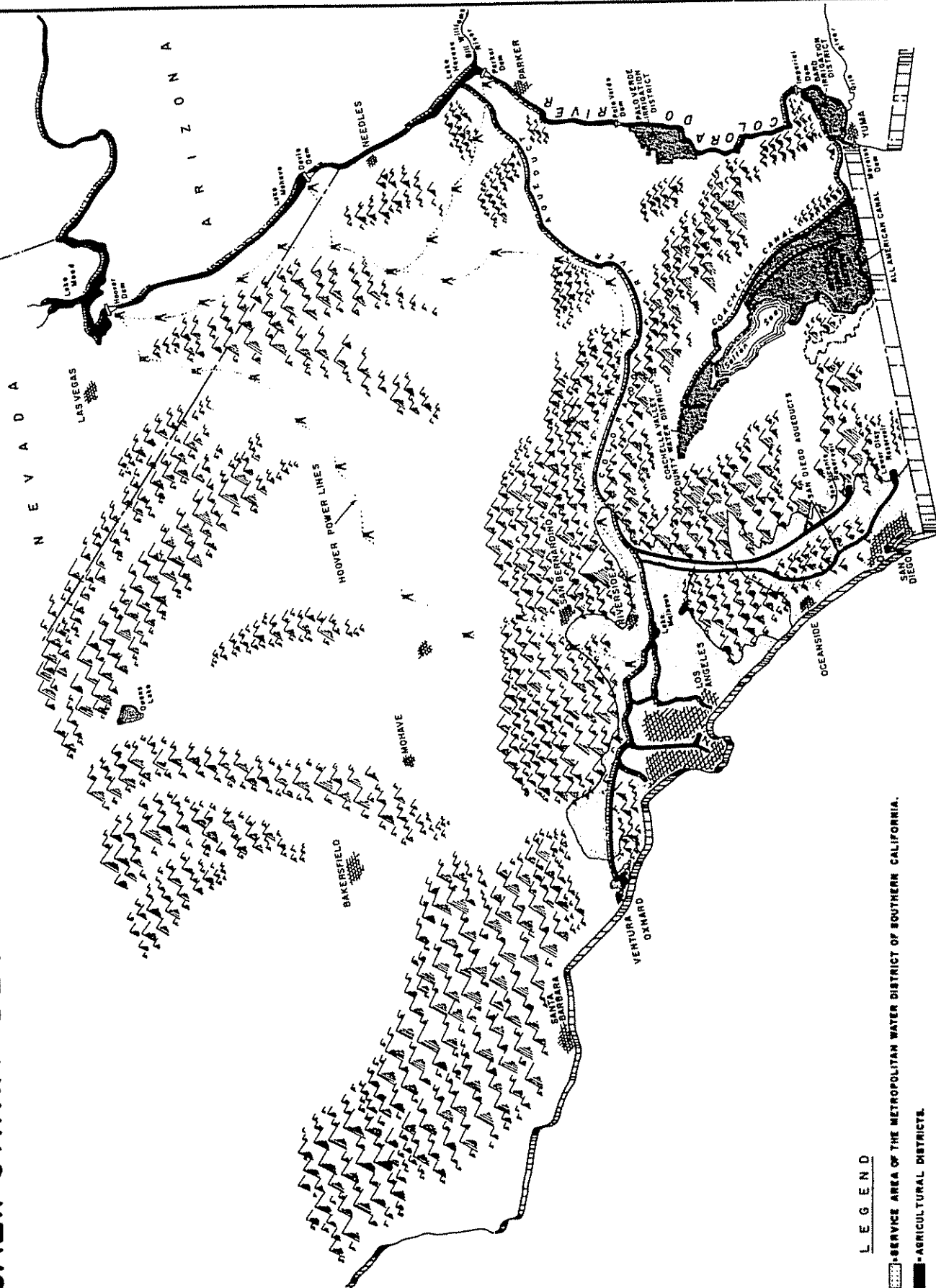
The Board commenced the salinity studies in connection with this report in the early part of 1969. The necessity to seek

FIGURE

SALINITY AT SELECTED STATIONS WITHIN COLORADO RIVER BASIN



CALIFORNIA DEVELOPMENTS USING COLORADO RIVER WATER



Presented by Colorado River Guard

solutions to Colorado River salinity problems was also recognized by the State Water Resources Control Board at its Colorado River Water Quality Briefing Conference held on September 17, 1969. At that time, Mr. Kerry Mulligan, Chairman of the State Water Resources Control Board, stated the need for a report on salinity problems in the Colorado River Basin and on the potential solutions. The State Water Resources Control Board agreed that the Colorado River Board was the proper agency to prepare such a report. Subsequently, a memorandum of understanding was signed. The Colorado River Board agreed to make the necessary studies and to prepare the report; the Department of Water Resources to consult, review, and comment on the report; and consultations and meetings to be held as necessary with the State Water Resources Control Board and the Colorado River Basin Regional Water Quality Control Board. This report has been completed in conformance with the memorandum of understanding.

This report is of a reconnaissance level and makes maximum use of published and unpublished works of other agencies. No attempt has been made to raise legal issues as they are beyond the scope of this report. All published sources used are listed in the Appendix. The principal agencies supplying information and data were the U. S. Geological Survey, U. S. Bureau of Reclamation, Federal Water Quality Administration, Palo Verde Irrigation District, Imperial Irrigation District, and The Metropolitan Water District of Southern California.

During preparation of this report, constructive comments were received from the latter three agencies and from the Los Angeles Department of Water and Power, San Diego County Water Authority, Coachella Valley County Water District, and the California Attorney General.

CHAPTER II

HISTORICAL ACTIONS RELATING TO SALINITY

Colorado River Compact

The 1922 Colorado River Compact apportioned water between the upper and lower parts of the Colorado River Basin. It contains no explicit provision regarding water quality.

Mexican Water Treaty

The Mexican Water Treaty, ratified in November 1945, provides for "a guaranteed annual quantity of 1,500,000 acre-feet" of water to Mexico from the Colorado River System. The Treaty states that Mexico is to receive water "from any and all sources." A review of the records of presentations made by negotiators for each country to their respective governments indicates a difference in understanding with respect to water quality.

Upper Colorado River Basin Water Projects

A major plan for the development of the Upper Colorado River Basin was approved by Congress in 1956 in a bill called the "Colorado River Storage Project and Participating Projects." The plan called for the construction of several large dams, reservoirs, and hydroelectric generating plants on the Colorado River and its principal tributaries above Lee Ferry, and for an undefined number of "participating" reclamation projects within the Upper Basin.

The Colorado River Board testified before Congress that construction of the Upper Basin projects would have an adverse effect upon the salinity of the waters reaching California users, and that planning should take into account the salinity effects on

existing Lower Basin projects. This position was instrumental in obtaining language in the Act that directed the Secretary of the Interior to investigate and report periodically to Congress and to the Colorado River Basin states on water quality conditions of the Colorado River.

Amendments concerning the study of the river's water quality and specifying a schedule for reporting thereon also were inserted in authorizing legislation for the Navajo Indian Irrigation Project, the initial stage of the San Juan-Chama Project, and the Fryingpan-Arkansas Project. These projects provide both for in-basin irrigation developments and diversions out of the Colorado River Basin. It was hoped that, with the accumulation of basic information on water quality and analyses of effects of future projects, studies could be made of ways to alleviate salinity problems. To date, the Secretary has submitted four reports on water quality of the Colorado River Basin.

Minute No. 218, International Boundary and Water Commission

In the fall of 1961, the salinity of the Colorado River rose sharply in the water arriving at the International Boundary for Mexico as a result of the pumped drainage of highly mineralized ground water that began earlier in the year on the Wellton-Mohawk Project in Arizona. These highly saline waters from the Project were discharged into the river downstream of all United States diversions, but upstream of all Mexican diversions. The Mexican government immediately lodged strong protests with the United States Government over the river's salinity.

The United States and Mexico met to discuss the problem, and in 1965 entered into a five-year agreement that was embodied in Minute No. 218 of the International Boundary and Water Commission. The agreement provided for construction and operation of a channel that can bypass saline drainage water from the Wellton-Mohawk Project around the Mexican point of diversion at Morelos Dam. It also gives Mexico the right to decide when drainage water is to be bypassed, and further provides that during the period from October 1 to February 28, when Mexico is taking water at the minimum winter rate, the United States is to control waters reaching the limitrophe section of the river so that, without including Wellton-Mohawk drainage water, the flows will average the minimum winter rate of 900 cubic feet per second. Compliance with the Minute has resulted in total deliveries to Mexico in excess of 1,500,000 acre-feet per year.

The five-year interim agreement expires on November 15, 1970, and steps are now underway to extend the present agreement or to negotiate a new one.

Protection of Quality Under the Water Quality Act of 1965

The principal legislative act that sets forth the responsibilities of the states and the Federal Government with respect to water quality of interstate waters is the Water Quality Act of 1965 and amendments thereto. The 1965 Act required that each state establish water quality standards for interstate and coastal waters within the state. These standards include water quality criteria and a plan for implementation and enforcement and were to be submitted to the Secretary of the Interior for his approval by June 30, 1967.

Guidelines of the Secretary of the Interior

In May 1966, the Secretary of the Interior issued the "Guidelines for Establishing Water Quality Standards for Interstate Waters" under the Water Quality Act of 1965. These guidelines advised the states of the contents of the standards deemed necessary for acceptance by the Secretary.

The guidelines stated that the purpose of establishing water quality standards was to "enhance the quality of water" and in no case would standards be acceptable that provided for less than existing water quality. Further, all wastes amenable to treatment must be treated prior to discharge into any interstate water regardless of the water quality criteria or uses adopted.

Development of Colorado River Policies and Standards

In 1966, representatives of all seven Colorado River Basin states met to consider a common framework of guidelines so that the water quality standards for the Colorado River System, to be set separately by the seven states of the basin, would be mutually compatible.

The conferees did not attempt to settle the very difficult problem of establishment of numerical criteria for salinity. Instead, it was agreed that the proposed water quality standards should state the criteria for salinity in qualitative terms only, pending the acquisition of more data and knowledge. The conferees finally agreed on January 13, 1967, to a document entitled "Guidelines for Formulating Water Quality Standards for the Interstate Waters of the Colorado River System."

Based upon the guidelines, the California State Water Quality Control Board adopted policies and standards for the Colorado River and submitted them to the Secretary of the Interior. The other basin states also adopted standards which were essentially based on the guidelines.

Numerical Criteria for Salinity

The conferees of the seven Colorado River Basin states further considered the question of setting numerical limits on salinity, and at a meeting on November 15, 1967, passed a resolution that contained the following:

"RESOLVED, that the Conferees urge the completion of water quality reports of the federal agencies at the earliest practicable date, and that thereafter the basin states and federal agencies again consider the setting of salinity standards for the Colorado River System; and be it further

"RESOLVED, that the Conferees hereby urge the FWPCA to consider the approval of the water quality standards of the seven Colorado River Basin states conditioned upon ultimate establishment of acceptable numerical salinity standards after completion and consideration of FWPCA and Bureau of Reclamation reports presently underway."

At the time this statement was agreed to, it was expected that the Federal Water Quality Administration report, which is the major water quality study effort on the basin, would be completed within a year. To date, this report has not been released. The Bureau of Reclamation report, "Quality of Water Colorado River Basin" Progress Report No. 4, January 1969, has been released.

The statement of position by the representatives of the seven Colorado River Basin states was apparently recognized by the Federal Government. Shortly thereafter on January 30, 1968,

Secretary of the Interior Stewart Udall testified at hearings of the House Interior and Insular Affairs Subcommittee on Irrigation and Reclamation regarding water quality standards. At that time, he presented a statement that contained the following sentence:

"Before discussing this problem further, I would like to state that salinity standards will not be established /for the Colorado River/ until we have sufficient information to assure that such standards will be equitable, workable, and enforceable."

The same position was reiterated by Assistant Secretary of the Interior Max Edwards in a letter dated February 12, 1968. At this time he also stated that the Department of the Interior intends to pursue active programs to lay the foundation for setting numerical standards at some future time.

California's proposed standards for the Colorado River were accepted by Secretary Udall on January 9, 1969, with the requirement that the state provide certain additional quality parameters such as numerical thermal values. These standards, of course, contain no numerical limits on salinity.

If the states do not adopt numerical criteria for salinity, after a complex procedure including conferences with the states, the Secretary could establish the criteria himself. Should standards accepted by the Secretary be violated, the Secretary could seek to enjoin such a violation. While the steps in such a proceeding are too lengthy to fully describe here, the essence of such a procedure is that the Secretary, through conferences and public hearings, seeks to effect a solution which ultimately may be enforced by court action.

Anti-Degradation Statement

In February 1968, Secretary of the Interior Udall requested that each state include in its water quality control policy submitted for approval a statement declaring that no further water quality degradation would be permitted under the standards approved. Most of the western states had some reservations as to the content of such a statement, and these were later resolved.

Accordingly, the California State Water Resources Control Board adopted an anti-degradation statement to be included in all of the state's water quality control policies. This statement was accepted by the Secretary of the Interior on January 9, 1969. The essential points of that statement are contained in the following excerpt:

"Existing high quality of water will be maintained until it has been demonstrated to the State that any change will be consistent with maximum benefit to the people of the State, will not unreasonably affect present and anticipated beneficial use of such water and will not result in water quality less than that prescribed in the policies."

CHAPTER III

HISTORICAL AND PRESENT SALINITY

The mineralization or salinity of the Colorado River is not a special occurrence but is common to all rivers; however, the salinity of the lower Colorado River is considerably higher than that of most major rivers. All natural waters contain dissolved mineral matter, as water in contact with soils or rock will dissolve some rock materials. The quantity of dissolved minerals in a natural water depends primarily on the type of rocks or soils through which the water has passed and the length of time of contact.

The concentration of dissolved solids in the Colorado River has been increased by the activities of man, primarily through application of water to lands for irrigation, and return of the diverted water's salts to the river together with those salts picked up in the process. Other man-caused sources of salinity are drainage from mines, abandoned wells, oil field and other industrial discharges, and municipal wastes.

Both the natural and man-made sources have been analyzed and projections have been made of the future salinity of the river, based on the sources of mineralization. Production of dissolved salts within the basin is generally related to the annual runoff; however, the relationship is imprecise. At Lee Ferry the total salt load can vary within about one million tons for any one value of annual runoff.

The weighted average salinity^{1/} occurring at various locations on the Colorado River and its major tributaries during the period 1963-67 is shown on Figure 1. As the figure indicates, the salinity of the river and tributaries generally increases from headwater locations to downstream locations.

Causes of the River's Salinity

The changes in salinity indicated on Figure 1 are caused by the increasing input of salts and the consumptive use of water as the water flows downstream. The variations in salinity between the streams are also due to variations in the solubility of minerals in the watershed rocks and soils.

Natural Origin Sources of Salinity

The salts of natural origin are produced from sources that may be classified as either diffuse or point. Diffuse natural sources are characterized by salt accretions from large drainage areas. Point sources include springs or seeps and highly mineralized streams that flow from a small area. An analysis by the U. S. Geological Survey concluded that, in the absence of any use by man, the Colorado River at Lee Ferry would have had a long-term weighted average salinity of around 250 ppm (containing about 5,100,000 tons per year in a virgin undepleted flow of about

^{1/} This report follows a system of reporting the river's salinity, or total dissolved solids, in parts per million parts of solution (ppm), although much of the analytical data used state concentrations in milligrams per liter (mg/l). Except for higher concentrations above about 7,000 ppm, the two systems are numerically equal. Most of the total dissolved solids data were determined by the "sum of constituents" method, and some were determined by the "residue" method with drying at 180°C. U. S. Geological Survey paper, W.S.P. No. 1473, discusses these methods.

15 million acre-feet per year, based on the 1914-57 hydrologic period). During the same time period, the river's actual salinity was about 500 ppm.

At Hoover Dam about 77 percent of the salt of natural origin is from diffuse sources, and about 23 percent is from point sources. This ratio is significant, inasmuch as point sources are susceptible of control whereas diffuse sources generally cannot be controlled.

Diffuse Sources. The high mountain areas of the Colorado River Basin are almost entirely made up of weather resistant, crystalline rocks containing constituents of very low solubility. As a result, the runoff from the high mountain areas has a low salinity. However, due to the large areas contained in these portions of the watershed, the total tonnage of salt picked up is significant. The minerals in the watershed at lower elevations in the basin generally have a relatively high solubility which results in runoff from precipitation on these lands having a higher salinity than the water from the higher elevations.

The quantity of ground water, and concentration of the dissolved solids in the ground water, entering the streams greatly influences the salinity of the water in the streams. During periods of low flow, much of the water in most streams is emerging ground water containing a higher salinity than direct runoff originating from precipitation or snowmelt. As a result, the streams reach their seasonal peak in salinity concentrations during the low-flow periods of each year.

During the 1914-57 period, diffuse sources have contributed an average of approximately 4,200,000 tons of salt per year to the Colorado River upstream of Lee Ferry. The Colorado River between Lee Ferry and Hoover Dam shows an average annual gain of 1,412,000 tons of dissolved solids from diffuse sources for the period 1941-66. Approximately 570,000 tons of this total originate in tributaries where salinity records are available. The balance of 843,000 tons probably originates from unmeasured flows and from soluble deposits in Lake Mead.

Between Hoover and Imperial Dams, the only sizable inflow containing salts from diffuse sources is the Bill Williams River, which has an average annual flow of about 70,000 acre-feet into Lake Havasu, together with an average annual salt load of 52,000 tons.

Point Sources. Many thermal springs and other natural point sources discharge highly saline flows into the basin's streams. While their combined flow is relatively small, their net effect upon the river's salinity is important. The annual water and dissolved solids contributed by all known natural point sources in the Upper Basin is 53,000 acre-feet and 890,000 tons, respectively. Between Lee Ferry and Hoover Dam, point sources contribute 232,000 acre-feet and 726,000 tons of dissolved solids annually. Records indicate that these values do not have large yearly variations. Point sources contribute approximately 15 percent of the total salt load, natural and man-made, reaching Hoover Dam. The natural origin point sources are tabulated in Table A in the Appendix, together with their water and salt contributions.

Reservoir Evaporation and Transmountain Diversions

The removal of water by evaporation increases the salinity of the remaining water by concentrating the water's salt content in a water volume reduced by the amount of evaporation. Before completion of the Colorado River Storage Project reservoirs within the last few years, evaporation from reservoir surfaces in the Upper Basin was minimal. During the 1963 water year, Upper Basin reservoir evaporation amounted to 320,000 acre-feet, which was responsible for 17 ppm of the salinity at Lee Ferry; this amounts to an increase of 5.3 ppm for each 100,000 acre-feet evaporated.

Lower Basin reservoirs have been evaporating water for many years. With the exception of Lake Mead, water surfaces of the Lower Basin reservoirs are almost identical from year to year, following essentially the same pattern of filling and drawdown each year. Lake Mead, the major storage reservoir for the Lower Basin, has experienced substantial fluctuations in storage. During the 1963 water year, evaporation from the three main Lower Basin reservoirs--Lakes Mead, Mohave, and Havasu--was estimated to be 944,000 acre-feet, which was responsible for 80 ppm of the salinity below Parker Dam; this amounts to an increase of 8.4 ppm for each 100,000 acre-feet evaporated.

Because diversions from the Upper Colorado River Basin into surrounding basins occur at or near the headwaters, the water diverted contains only a small portion of the minerals that would be released below Lee Ferry in the absence of diversions. Thus,

the effect on Lower Basin salinity of Upper Basin transmountain diversions is very similar to the effect resulting from increased reservoir evaporation--the concentration increases with increased diversions.

At the end of the 1957 water year, an average of 463,000 acre-feet of water and 38,000 tons of dissolved solids were being diverted out of the Upper Colorado River Basin in transmountain diversions. By the 1967 water year, this had increased to about 570,000 acre-feet of water and about 50,000 tons of dissolved solids. The net effect of such diversions on the river's salinity at Lee Ferry has been to increase the salinity by 19 ppm, as compared with natural conditions. This amounts to an increase of 3.3 ppm for each 100,000 acre-feet of water diverted.

Municipal and Industrial Uses

Municipal and industrial water use is fairly low at present in the Upper Basin, being 50,000 acre-feet during the 1965 calendar year. However, even under present low use rates, about 130,000 tons of dissolved solids were added to the stream system during the period June 1965 to May 1966 by Upper Basin municipal and industrial water users. This represented about one and one-half percent of the total salt load in the river at Lee Ferry. The large tonnage of salt added to the river relative to the small municipal and industrial consumptive use is due primarily to the magnitude and type of industry in the Upper Colorado River Basin, with the major source of salts originating in the

return to the river of large quantities of water that are used to separate minerals from ores by solvent extraction processes.

Municipal and industrial activities in the Lower Basin added about 23,000 tons of salts to the river during the 1965-66 period. Of this total, 6,000 tons were added to the river below Imperial Dam, the last point of diversion by California users.

Irrigation Uses

The water consumed in the process of irrigation is lost through evaporation during conveyance and by evapotranspiration both from the irrigated crops and from other vegetation between diversion of the water and its return to a stream. By this process, the river's mineral load is concentrated in a smaller volume of water and returned to the river. Also, additional minerals are added to the river's water by being dissolved while in transit through irrigated lands and back to streams; this latter process is called salt pickup through irrigation. Through these processes, the salinity of the water is increased.

The Federal Water Quality Administration estimated that for the period June 1965 to May 1966, 3,500,000 tons of salt were added to the river system through the process of salt pickup from irrigated lands in Upper Basin irrigation projects. Based upon the maximum dependable water supply, the salt from irrigation pickup was responsible for 40 percent of the river's salinity at Lee Ferry, while the concentrating effect of consumptively

using 2,100,000 acre-feet for irrigation was responsible for ten percent of the river's salinity.

The Federal Water Quality Administration recently conducted a study of salt pickup from irrigated areas in the Upper Colorado River Basin. In salt balance analyses made of individual areas for the year 1965-66, it was found that the salt pickup variation was from 0.1 to 3.5 tons per irrigated acre per year. The data developed from these analyses differ somewhat from that developed by the U. S. Geological Survey for the same area for the 1914-57 period, but confirm the general conclusion of the latter study that salt pickup is continuous. Table 1 lists the salt pickup developed in the aforementioned studies for a number of areas with a long history of irrigation. The salt pickup from all Upper Basin areas averaged about 1.7 tons per irrigated acre, based on the 1965-66 data. It should be noted that these values of salts picked up per irrigated acre are in addition to the salts diverted from the stream system and returned thereto.

TABLE I

SALT PICKUP FROM AREAS WITH A LONG HISTORY
OF IRRIGATION IN THE UPPER COLORADO RIVER
BASIN

(Tons per Irrigated Acre per Year)

Project Name or Area	Year Irrigation Began	Salt Pickup 1965-1966 <u>a/</u>	Average Annual Salt Pickup 1914-1957 <u>b/</u>
Grand Valley, Colorado	1881	8	---
Uncompahgre River Valley, Colorado	Prior to 1903	6.7	5.0
Duchesne River Basin, Utah	Prior to 1905	3.0	3.3
Big Sandy Creek Basin, Wyoming	1907	5.6	4.4
Castle Valley, Price River, Utah	1883	8.5	---
Lower Gunnison River Valley, Colorado	1882	6.7	5.0
Ashley Creek, Utah	Prior to 1900	4.2	2.1
Little Snake River Basin Dixon to Baggs, Colorado	Prior to 1902	0.5	1.2
Tomichi Creek Basin, Parlin to mouth, Colorado	Prior to 1900	0.3	---
Florida, Los Pinos, and Animas drainage areas, Colorado	Prior to 1913	0.2	---
La Plata River Basin, New Mexico	Prior to 1913	0.3	1.4

a/ Federal Water Quality Administration open files, Denver, Colorado. The values in this column may be higher than long term average values because 1965-1966 was a year of above normal precipitation following a year of below normal precipitation.

b/ "Water Resources of the Upper Colorado River Basin - Technical Report" Geological Survey Professional Paper 441, Iorns, et al.

Of striking significance are the records of the Grand Valley and Uncompahgre River Valley areas. Irrigation began in the Grand Valley in 1881. After more than 80 years of continuous irrigation, observed salt pickup in 1965-66 was approximately eight tons per irrigated acre per year. In the Uncompahgre River Valley, irrigation began prior to 1903, and the observed salt pickup during 1965-66 from this valley amounted to about 6.7 tons per irrigated acre per year.

Based on records developed during the course of the Federal Water Quality Administration's analysis, it has been concluded that salt pickup from irrigated areas will continue indefinitely, with the amount of dissolved salts added from each irrigated area being dependent upon soil mass and underlying geologic formations, as well as on the volume of applied water.

In a 1963-64 study by the Federal Water Quality Administration, it was found that salt contributed from irrigation in the Lower Basin during that year varied from 0.5 ton per irrigated acre on the Colorado River Indian Reservation, to 2.1 tons per irrigated acre from the Palo Verde Irrigation District, and 2.3 tons per irrigated acre from the Virgin River irrigated lands. Because the Indian Reservation irrigated acreage was rapidly increasing during the period tested, the data may not truly represent the long-term pickup of salts from that area. Further, a portion of the salt added by Palo Verde Irrigation District was caused by deepening existing drains which lowered the groundwater table and resulted in a removal of salt that had been

temporarily stored in the ground water. Upon completion of the Cibola cut, a new channel for the river in the area, the Palo Verde drain outlet may be lowered several feet, resulting in additional draining of high water-table areas. After the District's water table is stabilized at a lower level, it is expected that the salts picked up from the lands will be less than one-half the value measured in 1963-64.

During the period November 1963 to October 1964, irrigated agriculture in the Lower Basin between Parker and Imperial Dams added about 197,000 tons of salt to the river.

Phreatophytes, River, and Backwater Areas

Through water lost to the river system from consumption by phreatophytes and by evaporation from the river's water surface and its backwater areas, the river's salinity increases by concentrating salts into a smaller volume of water. Water is lost to the river system from these causes in both the Upper and Lower Basins; however, the loss is of much greater significance in the Lower Basin below Davis Dam. The U. S. Geological Survey has recently estimated that water consumed by phreatophytes and lost by evaporation from the river's surface, excluding evaporation from Lake Havasu, averages 580,000 acre-feet per year between Davis and Imperial Dams, and amounts to about seven percent of the water currently released at Hoover Dam. Present losses between Imperial Dam and the Northerly International Boundary amount to about 50,000 acre-feet, or 3.2 percent of the water passing Imperial Dam for delivery to Mexico.

Due to the small amount of salts added to the contents of the river between Davis and Imperial Dams in relation to the total salt load of the river, the effect of evaporation and phreatophyte losses on the river's salinity is approximately proportional to the ratio of volume of losses to total river flow volume. Present losses between Davis and Imperial Dams exclusive of evaporation at Lake Havasu result in an increase in the overall salinity concentration of approximately 70 ppm, or about 8 percent of the salinity at Imperial Dam. Most of these losses are not salvageable.

The Lower Colorado River Management Program proposed by the Bureau of Reclamation plans on reducing losses by clearing 42,000 acres of phreatophytes and by eliminating some of the shallow backwater areas as part of a balanced work program combining flow management, recreation, and fish and wildlife preservation and enhancement. Completion of the work remaining in the proposed program between Davis and Imperial Dams is estimated by the Bureau to salvage approximately 220,000 acre-feet per year. Prevention of this loss would reduce salinity at Imperial Dam by about 30 ppm, amounting to about three percent of current salinity at present levels of water use in the Lower Basin.

Between Imperial Dam and the Northerly International Boundary, completion of the Management Program would prevent losses of about 25,000 acre-feet annually, reducing the salinity at the Northerly International Boundary by an additional 13 ppm, or one percent.

Salinity of Water in the Upper Basin

All of the salinity effects in the Upper Basin are reflected in records at the Lees Ferry station on the Colorado River in northern Arizona. The salt load passing Lee Ferry, Upper Basin-Lower Basin division point located one mile downstream of Lees Ferry, averaged 3,155,000 tons per year for the period 1941-66, and has been estimated to be around 3,700,000 tons per year for the period 1914-57, adjusted to the 1957 level of development. This latter estimate was developed by the U. S. Geological Survey using correlation methods and statistical studies.

There are several hydrologic periods pertaining to the Colorado River that have been used by various agencies for determining hydrologic conditions for either long-term water supply analyses or in salinity analyses. The Bureau of Reclamation and the Federal Water Quality Administration in their current salinity studies on the Colorado River have been using the 1941-66 and 1942-61 hydrologic periods. Average annual virgin flows at Lee Ferry for these periods are 13.5 and 13.4 million acre-feet, respectively.

These flows are lower than most that have been used for estimating water supply for project development. The Bureau of Reclamation has used a long-term period which commenced near the turn of the century with an average virgin flow at Lee Ferry of 15.1 million acre-feet per year for its water supply studies. Studies by other agencies have referred to average annual virgin flows of 14.6 million acre-feet for the 1914-65 period, 13.8

million acre-feet for the 1922-69 period, and 13.0 million acre-feet for the 1931-69 period.

The analysis made in this report is based on studies of the water supply of the Colorado River which indicate that, considering all known factors, the dependable average annual virgin flow at Lee Ferry is no more than 14 million acre-feet. With this virgin flow, the mean annual salt load under current (1963-67) conditions of development at Lee Ferry was estimated to be 8.5 million tons.

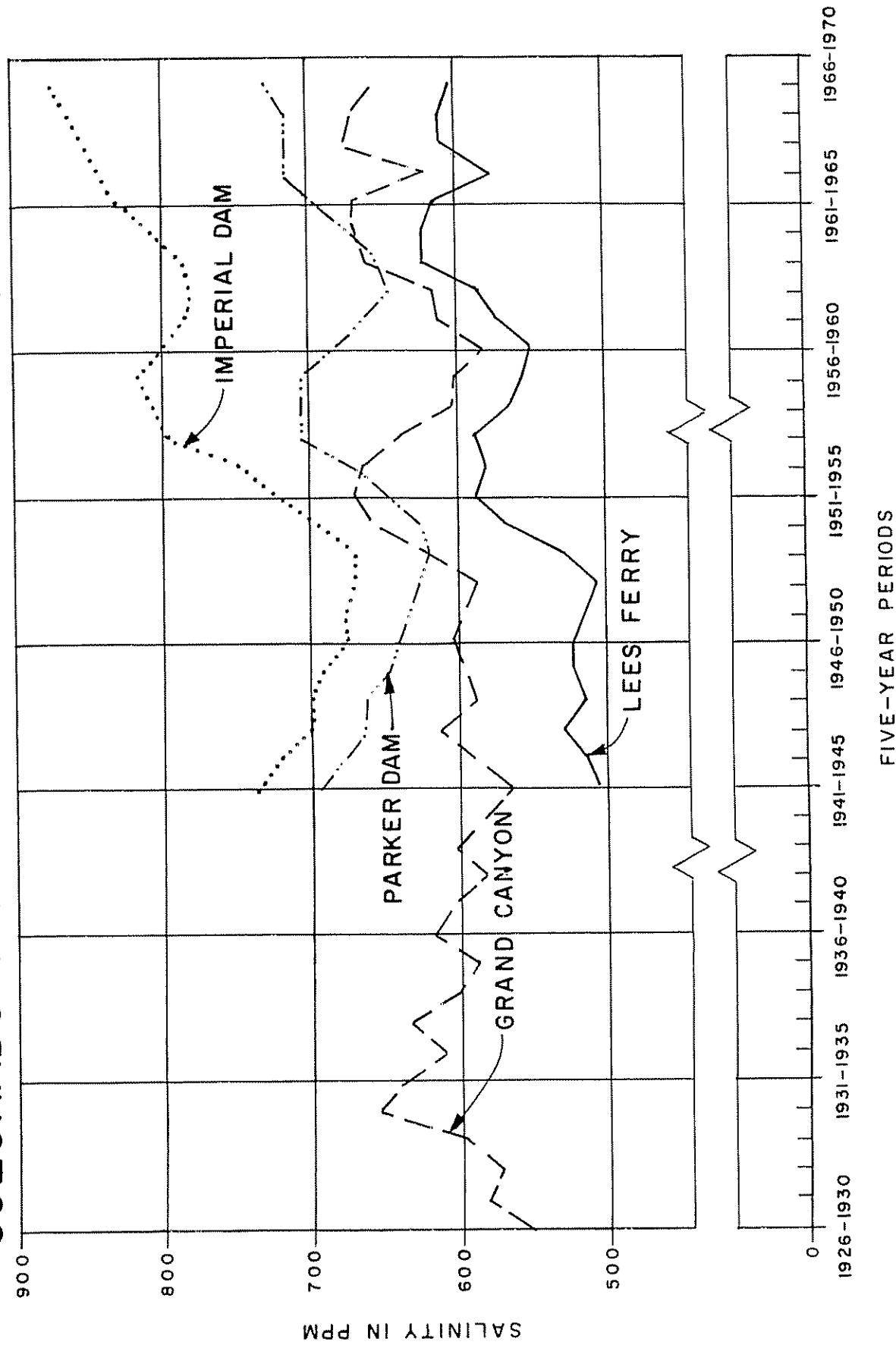
Salinity of Water in the Lower Basin

Salinity data have been collected at key stations on the main stem of the Colorado River since 1941. Although there have been some dips, these data indicate an overall trend of rising salinity since the early 1950's.

Figure 3, "Five-Year Moving Average Salinity, Colorado River Below Lees Ferry, Arizona," shows the effect of location on historical changes in salinity. The moving averages tend to eliminate some of the fluctuations of the annual data. Four stations on the river are plotted: Lees Ferry, Grand Canyon, Parker Dam, and Imperial Dam. The data at three of the stations began in 1941; thus, the initial point for the curves is 1945. Data for the station at Grand Canyon began in 1925.

The Lees Ferry and Grand Canyon data show a gradual convergence in the salinity of the river over a period of time. Salinity curves for Parker and Imperial Dam sampling points, however, diverge with time, indicating that changes have occurred

FIVE-YEAR MOVING AVERAGE SALINITY, COLORADO RIVER BELOW LEES FERRY, ARIZONA



in the factors contributing to salinity between these two points. The major factors are diminution of surplus flows starting in the late 1950's, increasingly larger quantities of water being consumed between the two points, and addition of more salts in the river between the two points. For the five-year period ending with 1955, the difference between Parker and Imperial Dam stations was 75 ppm. For the period ending with 1966, the difference was 130 ppm. When the above factors become stabilized, the differential in the river's salinity between the two points should become relatively constant.

Also of significance in analyzing the curves is the two-year lag indicated in increases or decreases in salinity at these two stations as compared with changes occurring at the two upstream stations. This time lag evidently reflects the dampening effect of storage in Lake Mead. It is significant that there is a transmission of variations in salinity at Lees Ferry and Grand Canyon being passed through Lake Mead to the lower river.

Table 2 shows the source of salts arriving at Lee Ferry, an approximation of the movement of salt between Lee Ferry and Imperial Dam on a pro forma basis with an average annual virgin flow of 14 million acre-feet per year and the 1963-67 level of man's activities.

Variations in Salinity at Imperial Dam

Due to the large volume of reservoir storage now available in the Colorado River Basin, extreme annual fluctuations that had historically marked the salinity of the Lower Colorado

TABLE 2

PRO FORMA SALT LOAD OF COLORADO RIVER AT SELECTED STATIONS
 (Annual Average in Thousands of Tons
 Under 1963-67 Development Conditions) a/

Sources of Salt Load Changes	Quantity of Salts	Total Salts in River at End of Reach
<u>Inflow to Lake Powell</u>		
Natural Diffuse Sources	4,000	
Natural Point Sources	900	
Irrigation Salt Pickup	3,500	
Municipal and Industrial	130	
Transbasin Diversions	- 50	8,480
Total	8,480	
Temporary Storage in Lake Powell	- 2,460	
Releases from Lake Powell		6,020
<u>Changes, Lee Ferry to Hoover Dam</u>		
Natural Diffuse Sources	1,400	
Natural Point Sources	700	
Total	2,100	8,120
Releases from Lake Mead		8,120
<u>Changes, Hoover Dam to Parker Dam</u>		
Natural Diffuse Sources	50	
Diverted by Metropolitan Water District	- 1,050	
Total	- 1,000	7,120
<u>Changes, Parker Dam to Imperial Dam</u>		
Irrigation	350	
Total	350	7,470

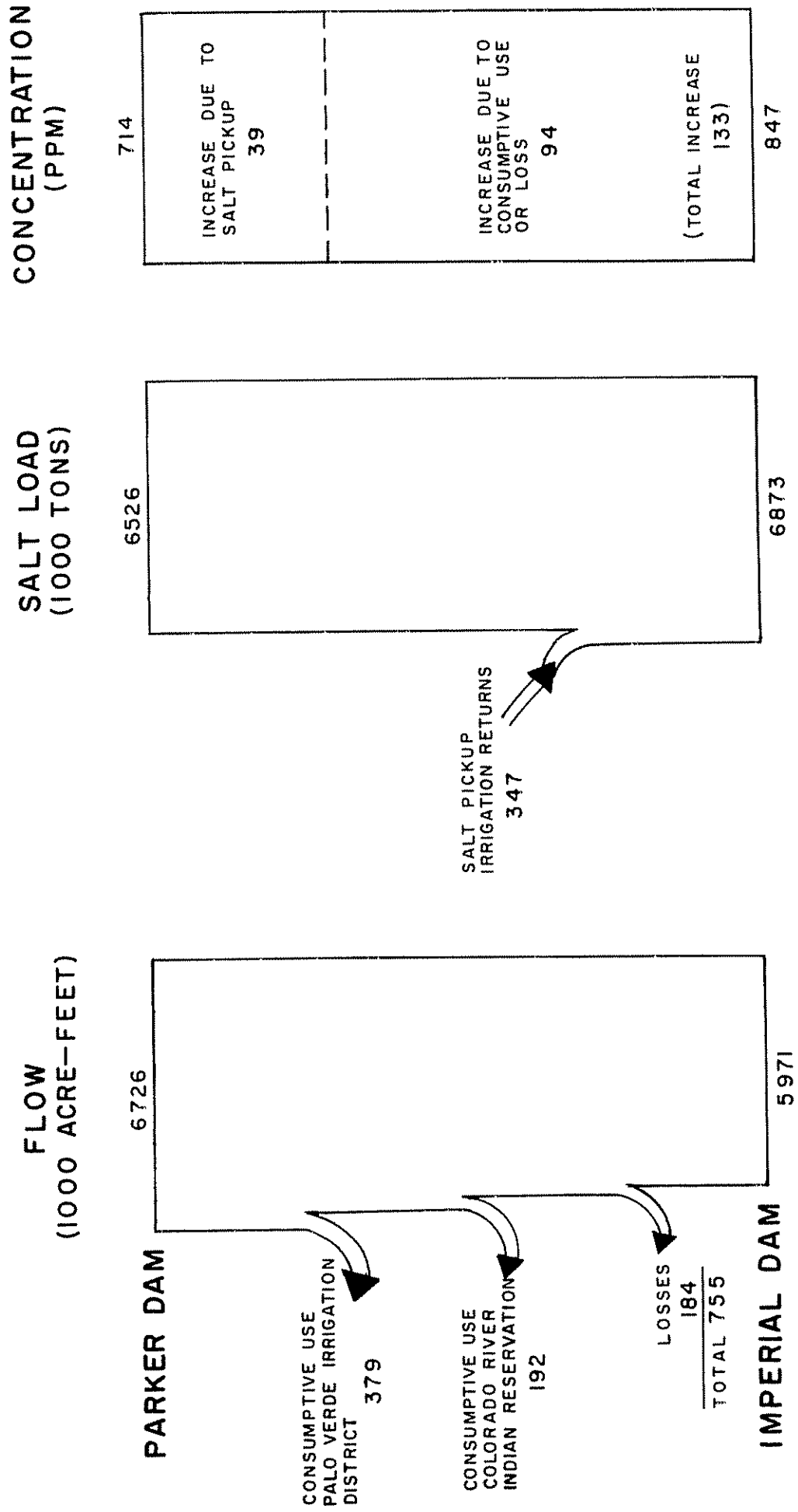
a/ Salt tonnages from natural sources based upon long-term average
 virgin flow of 14 million acre-feet.
 Salt tonnages from activities of man are based on current (1963-
 1967) levels of activity.

River have been considerably reduced. However, there remains a marked seasonal fluctuation in the river's salinity that affects the water users that divert at Imperial Dam.

Because of the adverse effect of these seasonal fluctuations on irrigation in the Imperial and Coachella Valleys, an analysis has been made on a monthly basis of the seasonal variations in salinity at Imperial Dam since 1961. The analysis included consideration of the river's flow and salt loading at Parker Dam, the diversions and returns to the river that occur between Parker and Imperial Dams, and the effect of water losses in the river between these two points. This analysis showed that almost all of the increase in salinity may be accounted for by the known diversions, returns, and losses.

The changes in salinity in this reach of the river for the 1962-63 period are indicated on Figure 4, "Change in Flow and Salt Load, Colorado River between Parker Dam and Imperial Dam." The added quantity of salt pickup resulting from irrigation in Palo Verde Irrigation District and Colorado River Indian Reservation amounted to an average of 347,000 tons per year, or about 5.3 percent of the total salt tonnage in the river at Parker Dam. However, the salinity increase between Parker and Imperial Dams was 133 ppm, amounting to an 18.7 percent increase. Only about 30 percent of this increase in concentration is due to salt pickup by irrigation and the remainder is caused by water consumptively used for irrigation and by other losses in this reach of the river.

CHANGE IN FLOW AND SALT LOAD, COLORADO RIVER BETWEEN PARKER DAM AND IMPERIAL DAM (ANNUAL AVERAGE FOR 1962-1968 PERIOD)



The possibility that seasonal filling and draining of backwater areas along the river may also contribute to seasonal variations in salinity was discussed with officials from the Bureau of Reclamation, Imperial Irrigation District, and Coachella Valley County Water District, and all available data were analyzed. Based on this information, it was concluded that periodic draining of backwater areas has only minimal effects on the river's seasonal variations in salinity. The cause of sharp rises in salinity that appear for several days at a time at Imperial Dam during winter months was not investigated, however, and needs further investigation.

Prior to 1961, large flows occurred in most months of most years that were in excess of Lower Basin uses and the Mexican Treaty allotment. The loss of dilution by these surplus flows has been a significant factor in salinity increases at Imperial Dam in recent years.

Table 3 contains a listing of average monthly flow at Imperial Dam for three consecutive eight-year periods from 1945 to 1968. These data indicate that substantial decreases in average monthly flow at Imperial Dam occurred from the earliest eight-year period to the latest, particularly during winter months. These reductions become significant when related to the quantity of irrigation returns entering this reach of the river. Prior to 1961, irrigation returns of the Colorado River Indian Reservation and Palo Verde Irrigation District in low flow winter months amounted to less than ten percent of the water arriving at Imperial Dam.

Table 3

AVERAGE MONTHLY FLOW COLORADO RIVER AT IMPERIAL
DAM FOR CONSECUTIVE EIGHT-YEAR PERIODS

(In Thousands of Acre-feet)

<u>Month</u>	<u>1945-1952</u>	<u>1953-1960</u>	<u>1961-1968</u>
January	1019	715	309
February	980	575	364
March	1075	738	581
April	937	796	623
May	931	750	572
June	868	733	622
July	871	847	716
August	855	813	698
September	818	655	536
October	863	553	418
November	851	489	307
December	<u>970</u>	<u>549</u>	<u>265</u>
Total	11,038	8,213	6,011

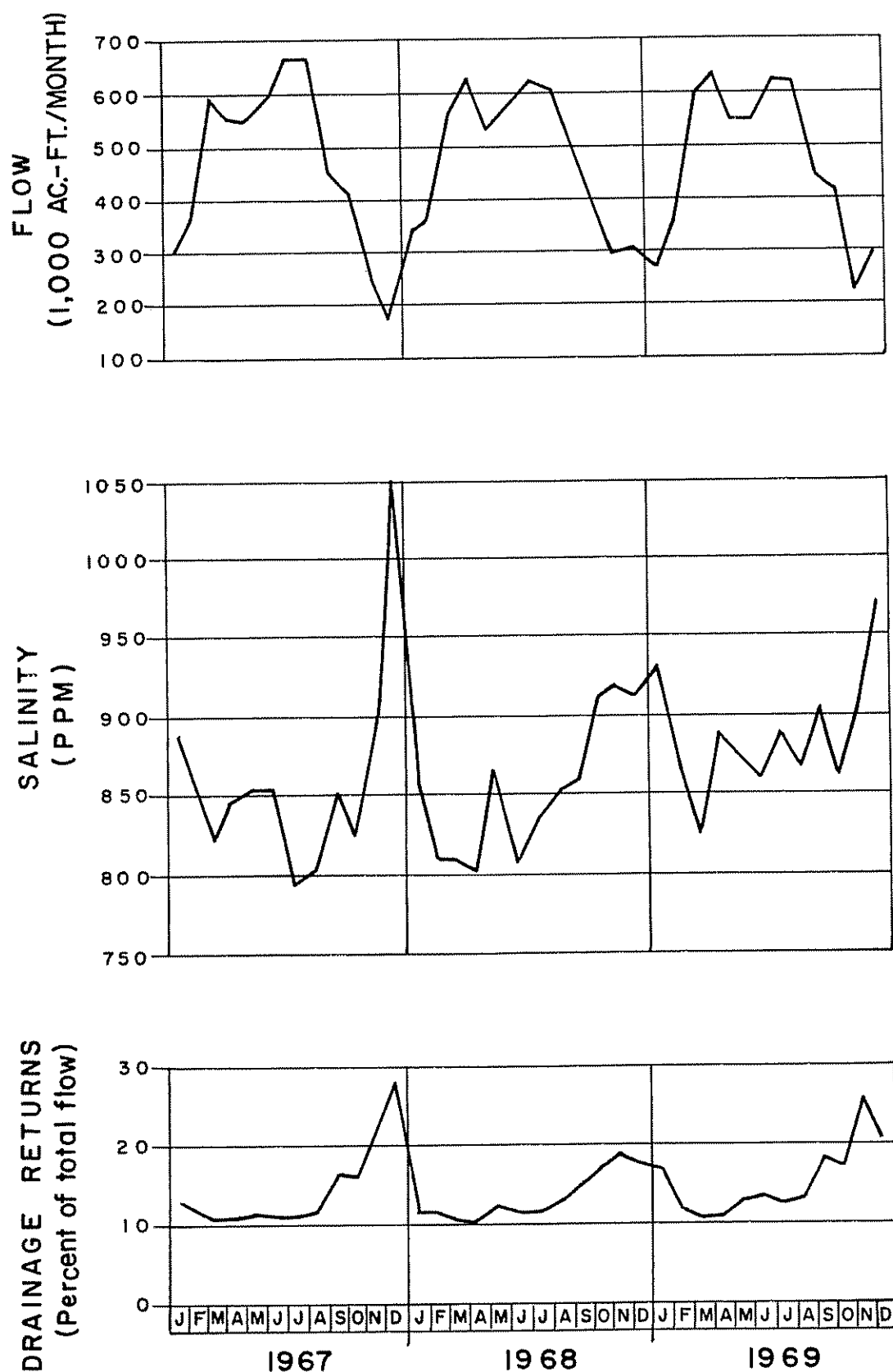
Since 1961, with the reduction in mainstream flows, irrigation returns have exceeded 20 percent of the flows arriving at Imperial Dam during some of the winter months of most years.

As drainage returns are of relatively high salinity, their effect has been to raise the salinity of the water at Imperial Dam. The effect would vary directly with the ratios between return flow and total flow; for example, in January, a month with a high ratio of return to total flow, the averages indicate that an increase of 32 ppm in salinity at Imperial Dam could be attributed to reduced river flows since 1961. During the spring and summer months, relative flows during the two latter eight-year periods did not differ as much, and the effect of variations in salinity were correspondingly less.

Figure 5, "Seasonal Variations in Flow and Salinity at Imperial Dam," illustrates the relationship between return flows, reduced river flows, and the river's salinity for the years 1967, 1968, and 1969. The figure shows that the river's salinity reaches its annual peak value during the winter months when irrigation returns often exceed 20 percent of the flow at Imperial Dam. The salinity drops during the spring and summer months when irrigation returns are only about ten percent of the flow at Imperial Dam.

Under conditions of continuing river operations that restrict river flows below Parker Dam to only those necessary to meet delivery requirements and mainstream losses, as has been the procedure for many years, the major variable factor responsible for

SEASONAL VARIATIONS IN FLOW AND SALINITY AT IMPERIAL DAM



seasonal variations in salinity at Imperial Dam appears to be the ratio of irrigation returns to total flow at Imperial.

Salinity of Water Available for Use in Mexico

The United States includes in its delivery computations return flow from the Yuma Valley delivered to the border at San Luis in Sonora, Mexico, as well as all return flows entering the Colorado River itself below Imperial Dam. The deliveries to Mexico are tabulated on Table 4. Prior to 1961, these return flows were not significant in most years and amounted to 13 percent of total flow to Mexico in 1960. However, when releases from storage in the United States were limited to downstream consumptive use, and the return flow from Wellton-Mohawk Project commenced, the proportion of return to total flow more than doubled, being 26 percent in 1961 and 30 percent in 1962. Since 1962, the return flows have been about 32 percent of the total delivery to Mexico. The decreased flows from storage and increased flows of higher salinity drainage water have had a major effect on the salinity of water to Mexico.

All drainage waters tend to be of higher salinity than the water source used for irrigation, but the pumped drainage from ground water in the Wellton-Mohawk Project has been exceptionally salty. Initial flows in 1961 of the Wellton-Mohawk drainage waters had an average annual salinity in excess of 6,000 ppm, but the salinity has been steadily dropping over time, reaching 4,100 ppm in 1969.

The effect of the Wellton-Mohawk drainage water was especially

Table 4

SOURCES OF COLORADO RIVER FLOWS TO MEXICO
(Acre-Feet per Year)

Calendar Year	From Above Imperial Dam	Return Flows Below Imperial Dam	Total ^{a/}	Return Flows as a Percent of Total
1960	2,179,700	327,730	2,507,430	13.1
1961	1,349,700	489,060	1,838,760	26.6
1962	1,380,150	596,720	1,976,870	30.2
1963	1,382,100	621,798	2,003,898	31.0
1964	1,133,200	522,230	1,655,430	31.5
1965	1,189,000	498,661	1,687,661	29.6
1966 ^{b/}	1,104,800	551,300	1,656,100	33.3
1967 ^{b/}	1,062,140	496,840	1,559,000	31.9
1968 ^{b/}	1,061,720	501,020	1,562,700	32.0
1969 ^{b/}	1,021,200	540,800	1,562,000	34.6

^{a/} Including flows crossing land boundary at San Luis and those discharged to the river below Morelos Dam.

^{b/} Figures from Report on Fourth Year's Operations for Solution of the Colorado River Salinity Problem Under Minute No. 213 of the International Boundary and Water Commission, November 17, 1969.

severe during the winter months when Mexico requests the minimum rate of deliveries permitted by the Treaty. During the first year of operation of the drainage project, Colorado River water, including return flows, reaching Mexico during the winter months was at a salinity of over 2,500 ppm. During summer months, when the flow of the Wellton-Mohawk drain amounted to less than ten percent of the river's flow to Mexico, the salinity was about 1,350 ppm.

On November 15, 1965, drainage from the Wellton-Mohawk Valley was discharged into a channel constructed in fulfillment of an agreement with Mexico, marking the beginning of the five-year period authorized by Minute No. 218 of the International Boundary and Water Commission.

The increase in salinity of Colorado River deliveries to Mexico, due largely to commencement of Wellton-Mohawk drainage flows in 1961, and the decrease in recent years, due to operations pursuant to Minute No. 218, are shown in Table 5. The average annual salinity at Imperial Dam is shown for comparative purposes.

Table 5

SALINITY AT IMPERIAL DAM AND THE
NORTHERLY INTERNATIONAL BOUNDARY(in parts per million) a/

Calendar Year	At Northerly International Boundary	At Imperial Dam
1959	760	750
1960	810	780
1961	1360	820
1962	1490	820
1963	1360	790
1964	1315	820
1965 <u>b/</u>	1375	920
1966	1227 <u>c/</u>	900
1967	1213 <u>c/</u>	850
1968	1194 <u>c/</u>	850
1969	1184 <u>c/</u>	880

a/ These values were obtained from a report of the International Boundary and Water Commission and were determined by applying conversion factors to electro-conductivity measurements made by the United States Geological Survey. These values differ from other values used in this report that were obtained by evaporating a sample and drying the residue at 130°C, or by the sum of constituents method.

b/ Minute No. 218 operation commenced in November 1965.

c/ Salinity at Northerly Boundary excluding waters bypassed at times of minimum winter deliveries to Mexico and waters bypassed voluntarily by Mexico.

CHAPTER IV

PROJECTIONS OF FUTURE SALINITY

Salinity of water in the Lower Colorado River Basin is expected to increase in years to come unless salinity control measures are executed. Expected growth of municipal, domestic, industrial, irrigation, and recreational uses will add mineral constituents and deplete the flow of the river. Water exports from Upper Basin headwaters will further deplete the flow. Salinity will increase through direct addition of mineral constituents and through concentration of mineral constituents as a result of depletions in the river's flow.

Even if timing and amount of all salt adding and concentrating developments were known, the river's future salinity could not be predicted with accuracy because of its widely fluctuating annual runoff and the inexact correlation between volume of runoff and salt load. The projections of future salinities were predicated upon long-term water supply and on runoff-salt load relationships. While the inherent limitations in the accuracy of the resulting projections are recognized, they are believed to represent a reasonable approximation of the river's future salinity.

Future Upper Basin Development

All phases of the Upper Basin's economy are expected to expand in the future, requiring increases in water uses. Several major water projects are now under construction and several others have been authorized and are awaiting funds for commencement of

design and construction. This category includes those authorized by the Colorado River Basin Project Act of 1968. In addition, many other inbasin projects that would develop water for irrigated agriculture and municipal and industrial uses are being studied. Transmountain diversions to the eastern slopes of the Rocky Mountains in Colorado and Wyoming, to the Bonneville Basin in Utah, and to the Rio Grande River drainage in New Mexico have been authorized or are being planned.

Projections of the magnitudes and types of future water uses in the Upper Basin have been made by the Bureau of Reclamation, the Upper Colorado River Commission, and Colorado River Board staff. Table B in the Appendix shows the most recent estimates of present depletions and future depletions by projects as developed by each organization. The historical and projected depletions, including transbasin diversions and reservoir evaporation, are plotted on Figure 6, "Historical and Projected Upper Basin Depletions." The Board's staff estimate for 1980 was based on modifying the Bureau of Reclamation estimate to reflect the slowdown in funding of reclamation projects in recent years.

The estimates for future industrial projects are based to a large degree on anticipated developments in the potential oil shale industry and other extraction industries, and for large thermal electric power plants. Some of the proposed transmountain diversions would also supply water for industrial projects. Future annual depletions for industrial projects vary from the projection of 444,000 acre-feet in 2030 by the Bureau of

HISTORICAL AND PROJECTED UPPER BASIN DEPLETIONS

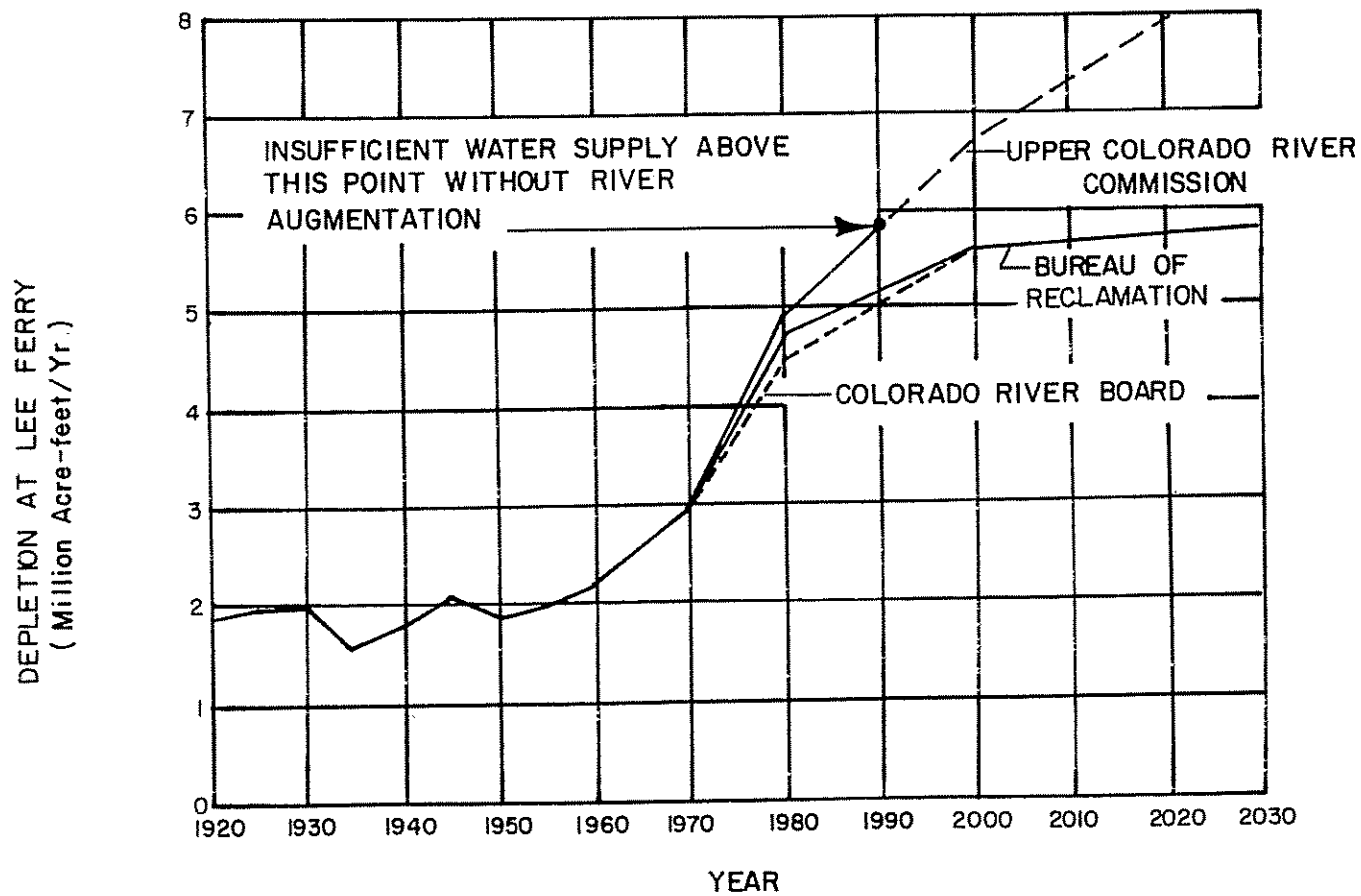


FIGURE 6

Reclamation to 711,000 acre-feet in 2020 by the Upper Colorado River Commission.

The magnitude of future industrial water use has been analyzed as part of the Federal-State Type I, Comprehensive Framework Studies. Preliminary projections from those studies show annual water use for large thermal electric power plants at 200,000 acre-feet by 1980, and 630,000 acre-feet from 2000 through 2020. Preliminary estimates for these studies do not project any appreciable water use by the possible oil shale industry through 2020 because of the Type I Study constraints. Based on this information, it appears possible that future depletions for industrial uses could exceed estimates by the Bureau of Reclamation if a sufficient water supply could be made available for these purposes.

Projected Salinity Increases Due to Upper Basin Developments

Computations of future salinity at Lee Ferry were made for each of the foregoing projections of Upper Basin depletions, using as the hydrologic base an average annual virgin flow of 14 million acre-feet and the following assumptions:

1. Existing uses would continue to add the same quantity of salts to the river system as at present.
2. Newly irrigated land would contribute two tons of salts per acre annually (see Appendix).
3. Projections do not include construction of salinity control projects such as are discussed in Chapter VI.
4. Depletions for irrigated agriculture would equal 1.5 acre-feet per acre annually at Lee Ferry (see Appendix).

5. Net future effects of Colorado River Storage Project reservoirs would be limited to evaporation only, and it is assumed that salts precipitated will balance salts brought into solution.

6. Depletions would be as projected by the Colorado River Board for 1980 and the Bureau of Reclamation for 2000 and 2030.

The results of the analysis are shown in Table 6. By 1980 the salinity at Lee Ferry would be 7 percent greater than the 1963-67 average, and by year 2000 it would be 31 percent greater.

Table 6

PROJECTED SALINITY AT LEE FERRY^{a/}

(in Parts per Million)

1963-67-----	610
1980 -----	650
2000 -----	800
2030 -----	820

a/ Assuming no salinity control projects.

Projected Salinity Increases Due to Lower
Basin Developments

Plans for major future water-using developments in the Lower Colorado River Basin are well identified. These plans include the addition of newly irrigated acreages along the river, primarily on the Indian reservations, increased uses along the Virgin River through the Dixie Project, and the diversion of large quantities of water away from the river for irrigation and municipal purposes by the Central Arizona and Southern Nevada Projects. It was

assumed that the salts contributed by municipal and industrial uses would be as estimated in the Type I, Comprehensive Framework Planning Studies for the Lower Colorado Region. All of the above projects, except the Central Arizona Project, will increase the river's salinity. The Central Arizona Project should not, since (1) it is unlikely that the water to be diverted would be released for dilution if not used by the project, and (2) any returns to the Colorado River would not occur for decades and, in any event, would enter the river through the Gila River, which joins below Imperial Dam.

The salt pickup from irrigation in the Palo Verde and Parker Valleys was assumed to be 1.0 ton per acre per year. Both present and future irrigation in the Virgin River area and Moapa Valley was assumed to contribute an annual salt pickup of 2.0 tons per acre. Completion of the Lower Colorado River Management Program, mentioned in Chapter III, prior to 1980 was also assumed, with its resultant reductions in water losses.

Starting with the projected salinity at Lee Ferry, Lower Basin gains and losses in flow and salt were algebraically added, proceeding downstream. The increase in salinity at the major diversion points due to projected increases in Lower Basin usage is shown on Table 7.

Table 7

SALINITY INCREASES ATTRIBUTABLE TO
LOWER BASIN DEVELOPMENTS

(in Parts per Million)

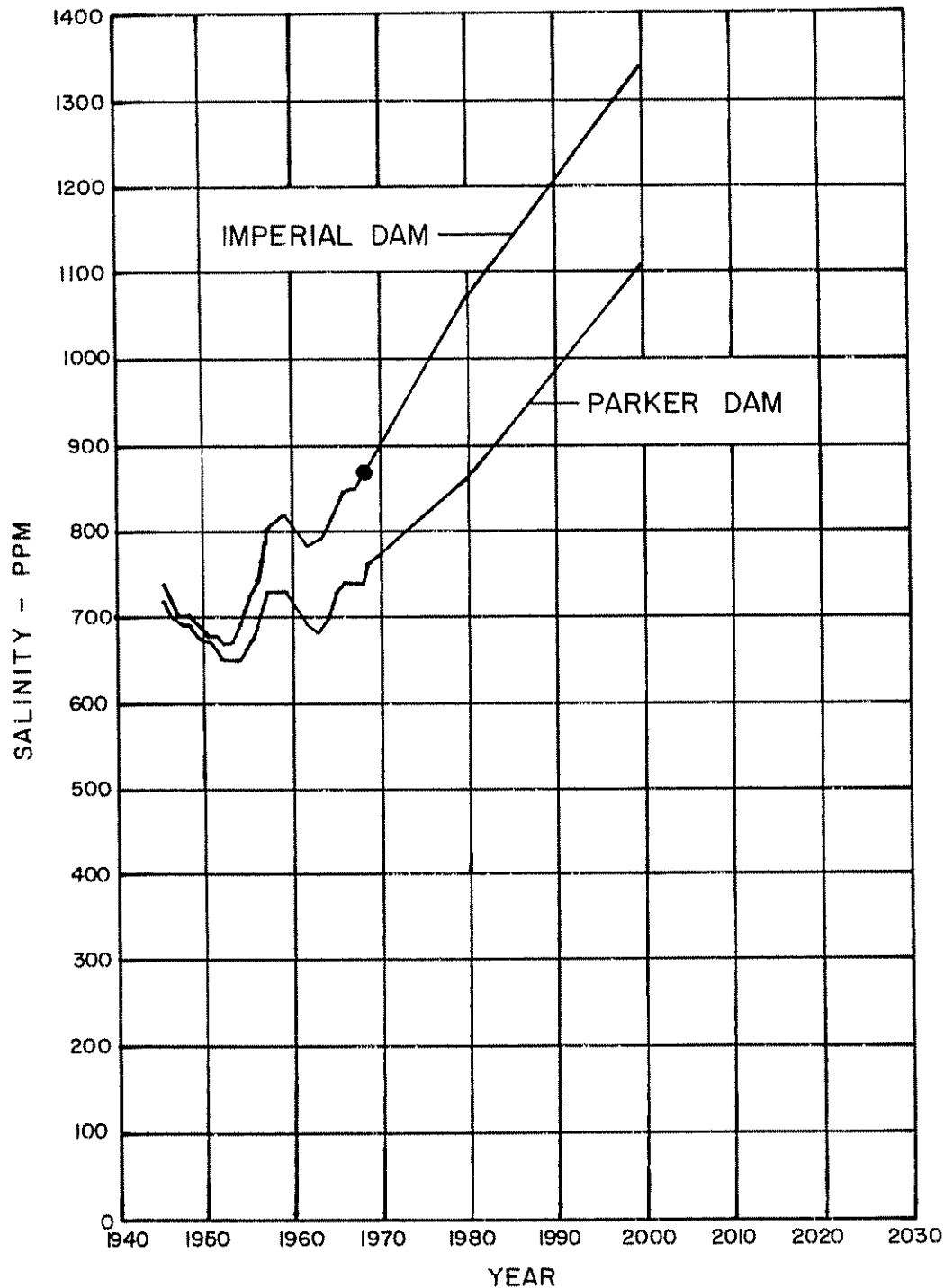
Location	Increase in Salinity ^{a/}		
	1980	2000	2030
Parker Dam	45	80	90
Palo Verde Dam	60	130	130
Imperial Dam	70	130	130

^{a/} Over 1963-67 salinity conditions.

Table 3 shows the projected salinity at major Lower Basin diversion points and at the Northerly International Boundary, reflecting usage in the entire Colorado River Basin and assuming that no salinity control projects are built.

The results from Table 3 indicate that the impact of mineral quality degradation on uses in the Lower Colorado River Basin will be severe. By 1980, the salinity at Parker and Imperial Dams is projected to increase by about 16 percent and 26 percent, respectively, over the 1963-67 average; by the year 2000, the increase will be about 50 percent and 53 percent, respectively. Historical and projected salinities at Parker and Imperial Dams are also shown on Figure 7, "Historical and Projected Salinity at Parker and Imperial Dams Without Salinity Control Projects." Estimates at the Northerly International Boundary were not carried past 1930.

HISTORICAL AND PROJECTED SALINITY AT PARKER AND IMPERIAL DAMS WITHOUT SALINITY CONTROL PROJECTS



NOTE - POINTS BETWEEN 1945 AND 1969 ARE
WEIGHTED FIVE-YEAR MOVING AVERAGES

Table 8
PROJECTED SALINITY ALONG THE LOWER COLORADO RIVER
WITHOUT SALINITY CONTROL PROJECTS

(In Parts per Million)

Location	Historical Average 1963-67	1980	2000	2030
Below Hoover Dam	730	830	1050	1090
Parker Dam	740	860	1110	1150
Palo Verde Dam	<u>a/</u>	910	1190	1230
Imperial Dam	850	1070	1340	1390
Northerly Int. B'ndry	1300	1350	<u>b/</u>	<u>b/</u>

a/ Records not available

b/ Not estimated

Table 8 shows salinity at Imperial Dam increasing from 850 ppm under 1963-67 conditions to 1340 ppm in year 2000, or 490 ppm. Table 7 shows that 130 ppm, or 26 percent of this increase, is attributable to Lower Basin developments, thus leaving the remaining 360 ppm, 74 percent of the increase, as the results of projected Upper Basin developments. Table 6 shows that salinity at Lee Ferry, which is the measure of the river's salinity as it leaves the Upper Basin, climbs from 610 ppm in 1963-67 to 800 ppm in year 2000, an increase of 190 ppm. Because of the changing salt-water relationship in the river, the 190 ppm increase at Lee Ferry results in the 360 ppm increase at Imperial Dam.

Table 8 also projects a 220 ppm increase at Imperial Dam between 1963-67 and 1980, and a 50 ppm increase at the Northerly International Boundary for the same period. This difference is due in part to the fact that 1963-67 was a high salinity period for the Northerly International Boundary, and to the following assumptions: (1) salinity of return flows below Imperial Dam will be lower than present values, and (2) operations will be such that return flows will be in salt balance by 1980.

As was discussed in Chapter III, the analyses reported herein have been based on a long-term virgin flow of 14 million acre-feet per year at Lee Ferry. Other long-term estimates are generally encompassed by a low of 13 million and a high of 15 million acre-feet per year. Accordingly, an analysis using these values was made of salinities that would occur at the selected Lower Basin stations in the future. Table 9 shows results of the analysis.

The effect of the smaller flow of 13 million acre-feet per year would be to increase the projected salinity in 1980 at Parker and Imperial Dams by about nine percent over salinities projected for that year using the 14 million acre-foot base flow. The larger flow of 15 million acre-feet per year would result in projected 1980 salinities at Parker and Imperial Dams being about eight percent less than they would be with a 14 million acre-foot per year flow.

Land Use and Ownership as Related to Salinity

The largest contributions to salinity are from natural runoff

Table 9

COMPARISON OF PROJECTED SALINITIES RESULTING
FROM VARYING PROJECTED FLOWS OF THE COLORADO RIVER

(In Parts per Million)

<u>Location</u>	<u>1980</u>		<u>2000</u>	
	Pro- jected Salinity	Percent Change from 14 maf/yr	Pro- jected Salinity	Percent Change from 14 maf/yr
<u>Colorado River at Parker Dam</u>				
13 maf/yr	940	+9.3	a/	-
14 maf/yr	860	-	1110	-
15 maf/yr	790	-3.1	1000	-9.9
<u>Colorado River at Imperial Dam</u>				
13 maf/yr	1170	+9.3	a/	-
14 maf/yr	1070	-	1340	-
15 maf/yr	990	-7.5	1210	-9.7

a/ Not computed as the water supply would be insufficient to meet commitments.

and point sources. The following tabulation shows that over two-thirds of the lands in the Colorado River Basin are owned by the Federal Government. Federally owned lands contribute substantially to the salinity problem.

Land Ownership in Colorado River Basin

	<u>Private</u>	<u>State, Local Government</u>	<u>Federal Government</u>
Upper Basin	29	4	67
Lower Basin	19	9	72
Aggregate	23	7	70

Irrigated agriculture adds the second largest salt load to the river. A number of the irrigated areas adding substantial salt loads are federal reclamation projects.

CHAPTER V

DELETERIOUS EFFECTS OF SALINITY ON CALIFORNIA USERS

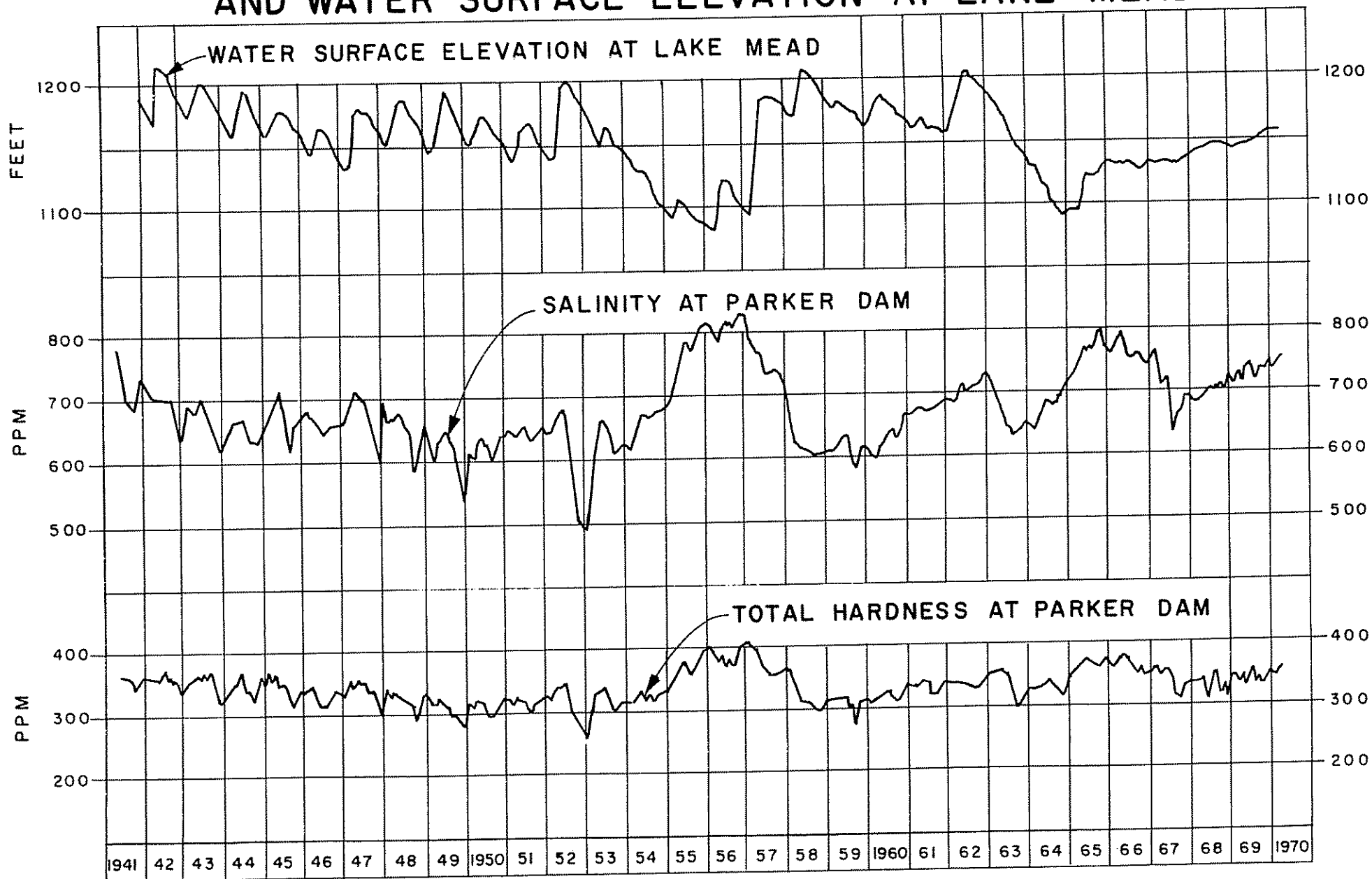
Except for minor uses, California's water users obtain Colorado River water through three major projects on the river. The Metropolitan Water District of Southern California pumps from Lake Havasu, formed by Parker Dam; Palo Verde Irrigation District diverts into its canal at the Palo Verde Diversion Dam, about ten miles northerly of the City of Blythe; and Imperial Irrigation District, Coachella Valley County Water District, Bard Irrigation District, and Yuma Indian Reservation all receive river water through the All-American Canal, heading at Imperial Dam.

While this report has defined the river's salinity problems in terms of total dissolved solids, in certain cases total salinity is not so important as the concentration of specific ions. Agricultural activity is most seriously affected by the concentration of sodium and chloride ions. Many urban uses are most seriously affected by calcium and magnesium ions responsible for the hardness characteristics of water.

The Metropolitan Water District of Southern California

Figure 8, "Salinity and Total Hardness at Parker Dam and Water Surface Elevation at Lake Mead," shows the variation in salinity and hardness of the water at Metropolitan Water District's Intake Pumping Plant at Parker Dam for the years 1942 through 1969, together with elevations of Lake Mead. In general, the figure shows a rise in salinity at Parker Dam with corresponding declines in the elevation of Lake Mead. This relationship

SALINITY AND TOTAL HARDNESS AT PARKER DAM AND WATER SURFACE ELEVATION AT LAKE MEAD



of Lake Mead stage to salinity of outflow is primarily the result of low inflows with relatively high salinity into Lake Mead. During the entire 23-year period, total dissolved solids have varied from a low of 495 ppm to a high of 840 ppm. Total water hardness has varied between 295 ppm and 400 ppm, a range which is in the "excessive hardness" category.^{2/}

The District has softened a large part of its water supply for many years. Chemical changes in the water upon softening are shown in Table 10, which compares the average mineral constituents for natural Colorado River water to that softened for 1968-69. The constituents primarily responsible for the hardness, calcium, and magnesium, were reduced in the softening process from 84 and 31 ppm, respectively, to 34 and 14 ppm, respectively. In the process the sodium ion increased from 108 to 201 ppm. Because of adverse effects of high sodium ion concentrations on plant growth, unsoftened water is preferable for irrigation use.

Problems associated with the use of Colorado River water for municipal and industrial purposes are high soap consumption, formation of objectionable scale in heating vessels, and damage

^{2/} The Federal Water Quality Administration's "Report of the Committee on Water Quality Criteria," April 1, 1968, stated "A singular criterion for the maximum hardness in public water supply is not possible. . . Public acceptance of hardness varies from community to community. A criterion for objectionable hardness must be tailored to fit the requirements of each community. Hardness more than 300-500 mg/l as CaCO₃ is excessive for public supply. A moderately hard water is sometimes defined as having hardness between 60 to 120 mg/l."

Table 10

ANALYSIS OF KEY CONSTITUENTS IN COLORADO RIVER WATER
DIVERTED AT LAKE HAVASU

(Average for Year Ending June 30, 1969)

Constituents	Symbol	Colorado River Water	
		Natural at Lake Havasu	Softened at La Verne
Calcium	Ca	84 ppm	34 ppm
Magnesium	Mg	31 "	14 "
Sodium	Na	108 "	201 "
Bicarbonate	HCO ₃	145 "	143 "
Sulfate	SO ₄	307 "	307 "
Chloride	Cl	98 "	102 "
Minor Constituents		17 "	16 "
Total Dissolved Solids ^{a/}		717 ppm	746 ppm
Total Hardness as CaCO ₃		337 ppm	142 ppm

^{a/} The total dissolved solids, in accordance with standard practice, are based on the conversion of bicarbonate to an equivalent amount of carbonate (0.4917 times amount of bicarbonate).

through corrosive attack on distribution pipelines and user plumbing systems and appliances. Studies indicate that increases in salinity would result in substantial costs to commercial, residential, and industrial users within the Metropolitan Water District from deterioration of plumbing and distribution systems and added costs of water treatment and conditioning. In addition, with increasing salinities, the District itself would incur direct costs for treatment of its water supply with chemicals. It is difficult to arrive at dollar values for the above detriments. Other investigators have estimated that the overall effects of all such costs within the District would be between \$5 and \$6 per acre foot for each 100 ppm salinity increase. This is equal to about \$5,500,000 per year, based upon present usage, for each 100 ppm salinity increase.

In addition to the economic impact on the District is the problem of an adverse effect on the taste of water that would result from an increase in salinity of the Colorado River, as millions of people would be affected within the District. The United States Public Health Service recommends salinity standards for drinking water which indicate as an objective that salinity should not exceed 500 ppm in cases where water of better quality is available. With projected increases to over 1,000 ppm, exclusive of any salinity control projects, the Public Health Service's recommended standards would be greatly exceeded.

Palo Verde and Bard Irrigation Districts and
Yuma Indian Reservation

Water diverted for the Palo Verde Irrigation District has a slightly higher salinity than the water at Lake Havasu. The

principal salinity problem in this area in the past has been caused by salts in the water in conjunction with a high water table. Open ditch drains have been constructed and have been recently enlarged to lower the water table to a safe depth; when the impaired flow conditions at the drain outlets are fully corrected, these measures should overcome most salinity problems in the valley.

Because of sediment deposition in the river's channel, the outlet elevation of the main drain from the Palo Verde Valley, through the Palo Verde Lagoon, is seven feet higher than it was in 1925. This not only has impeded the operation of the valley's drains, but in turn resulted in higher ground-water levels and reduced crop growth in portions of the valley. However, drainage operations since the completion of a new river channel downstream from Palo Verde Drain by the Bureau of Reclamation in March 1970 and the District's efforts in extending and deepening drains are already resulting in lower ground-water levels throughout the Palo Verde Valley.

Most of the valley's soils drain well, thus enabling salts to be leached out without the necessity of installing tile drains. However, it will be important that the infiltration capacity of the soil profile be maintained and that the District's drainage facilities be expanded as necessary to maintain the ground-water levels at sufficient depth below the surface to allow free draining of the soil root zone. Also, future increases in the salinity of the water supply will cause additional irrigation problems.

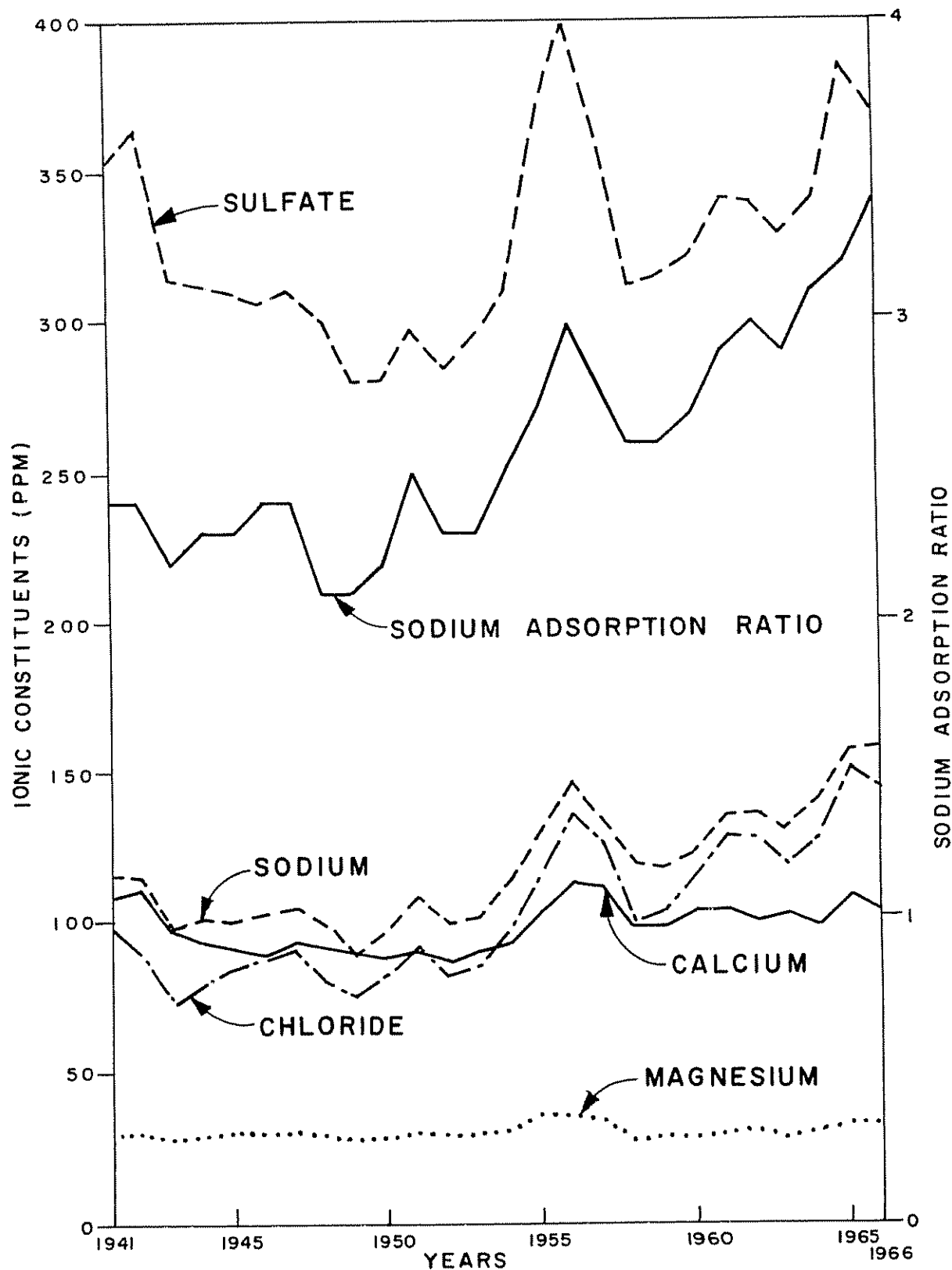
Even though the salinity of the water obtained from the All-American Canal for use within Bard Irrigation District and Yuma Indian Reservation is higher than the water available to Palo Verde Valley, their situation is similar. The main drain serving these areas was improved during 1969, which should result in a general lowering of the water table over much of the area. At the projected salinity levels, continued attention to soil drainage and accompanying drainage channels will be required in order for these areas to maintain their productivity.

Imperial Irrigation District and
Coachella Valley County Water District

Water users in Imperial and Coachella Valleys have experienced an increase in the salinity of water diverted for use in recent years. For example, during the period 1943-47, after completion of the All-American Canal, the river's salinity at Imperial Dam averaged about 700 ppm, but for the period 1965-69, salinity averaged 875 ppm.

Not only have total dissolved solids been increasing, but also the more harmful constituents have been showing marked increases. Figure 9, "Average Annual Concentration of Significant Ionic Constituents and Sodium Adsorption Ratio, Colorado River Water at Imperial Dam," shows the average concentration of principal ionic constituents for calendar years 1941 through 1966. This figure shows a general rise in the more harmful sodium and chloride ions. The impact of sodium ions in relation to calcium and magnesium ions is demonstrated by the Sodium Adsorption

AVERAGE ANNUAL CONCENTRATION OF SIGNIFICANT IONIC CONSTITUENTS AND SODIUM ADSORPTION RATIO COLORADO RIVER WATER AT IMPERIAL DAM



Ratio,^{3/} which is also plotted in Figure 9. This ratio is also increasing.

An additional problem presently causing much difficulty in Imperial and Coachella Valleys is related to seasonal variations in salinity that occur each year. The salinity of the water arriving at Imperial Dam is lowest during summer months and reaches its highest values in November and December of each year. Salinity levels that have been experienced in recent years have adversely affected germination of seeds and early growth and development of plants, with the salinity peaks that occur during winter months being particularly adverse.

Costs to Agricultural Users

Because of the predominance of clay and heavy loam soils in Imperial and Coachella Valleys, most farmers have installed tile pipe drainage systems and use irrigation water in excess of plant needs to leach out the salt to maintain a favorable salt balance in the root zone. These drainage systems cost from \$150 per acre to \$400 or more per acre, depending upon the required depth and spacing of the pipes. The amount of irrigation water needed for leaching increases in proportion to the salinity concentration of applied irrigation water. Any increase in salinity of irrigation water, therefore, results in an economic loss since more water is

^{3/} Sodium Adsorption Ratio. A ratio for soil extracts and irrigation waters used to express relative activity of sodium ions in exchange reactions with soil,

$$\text{SAR} = \text{Na}^+ / \sqrt{(\text{Ca}^{++} + \text{Mg}^{++}) / 2}$$

where the ionic concentrations are expressed in milliequivalents per liter.

required for the equivalent crop output. To overcome the effects of saline irrigation water by leaching requires that the soil be able to accept an increase in the amount of applied water.

Water percolating through the root zone removes applied fertilizers as well as salts, so, as additional water is applied for leaching, additional amounts of fertilizer must be applied to counteract this effect. Another cost associated with application of extra quantities of water for leaching out salts is the additional work required in making more frequent applications of irrigation water which must be done to get the larger quantities of water through the soil. Also, greater care must be exercised in leveling land to receive these waters.

The effect of some of these costs on the individual farmer has been estimated by various researchers in the past with varying results. One recent detailed study performed by the Federal Water Quality Administration estimated the economic effect of increasing salinity on agriculture by the "yield decrement" method, which was determined to be the least-cost alternative method for handling high salinity water. This method assumes no increased use of water for leaching, nor any acreage reduction to make water available for leaching purposes. The direct penalty cost is the reduction in value of yield due to the increase in salinity over the base level set at 760 ppm at Imperial Dam. Indirect penalty costs were evaluated for the effects of direct reduction of income in the agricultural sectors on other sectors of the economy. The sum of direct and indirect effects gives the total incremental

impact upon the economy. The study shows that penalty costs to California's agricultural users of Colorado River water and to other related sectors of the economy, based upon assumed higher salinity levels, would be as shown in the following tabulation.

<u>Salinity of Colorado River at Imperial Dam</u>		<u>Penalty to Economy (1970 Total Dollars per Year)</u>	<u>Unit Cost (Dollars per 100 ppm Over Base)</u>
Base	760	0	0
	1050	9,000,000	3,000,000
	1220	20,600,000	4,500,000

This method and resulting calculations do not represent the procedures being followed by California's agricultural users of Colorado River water. The users have made, and are continuing to make, large investments in drainage facilities to maintain their productivity and income levels under conditions of increasing salinity. Although considerable research has been done, it is evident that more work is required on the assessment of economic consequences of increasing salinity.

In addition to costs incurred by irrigators in California, the agricultural users of Colorado River water in Arizona and Mexico would also incur penalty costs.

Summary - Costs to California Users

The economic impact on California's users of Colorado River water, resulting from increases in salinity, may be approximated by adding estimated annual municipal and industrial user penalty costs of \$5 to \$6 million dollars to agricultural user penalty

costs of at least \$3,000,000 to \$4,500,000 per 100 ppm increase in salinity at Imperial Dam. The total penalty costs would be in the order of \$8 to \$10 million dollars for each 100 ppm increase in salinity over present levels.

With the projected salinity levels in the year 2000 at Parker and Imperial Dams of 1110 and 1340 ppm, respectively, without salinity control projects, the economic impact on California of the increased salinity would be in excess of \$40 million dollars per year.

CHAPTER VI

PROGRAMS TO CONTROL SALINITY

Other than by cessation of further development in the Colorado River Basin, future salinity increases can be prevented in three ways: (1) augmentation of the river with low salinity water supply, (2) removal of salts from the river or its tributaries, and (3) reduction of the loss of water by phreatophyte control and water salvage projects (discussed in Chapter III).

Augmentation

The principal methods for augmenting the river are importation of water from other basins having surplus water, modification of the weather to increase precipitation, and desalting of oceanic, brackish, or geothermal source water and its transfer to the river.

Transbasin Importation

In the early 1960's the Secretary of the Interior proposed to Congress the Pacific Southwest Water Plan, which contemplated importation of water from California's north coast into the Colorado River Basin. The Pacific Southwest Water Plan stimulated a number of other suggestions for importation of water into the Colorado River Basin from adjoining basins by individuals and organizations. Most of the suggestions involved diversions from the Columbia River Basin, Upper Missouri River Basin, and from Canada.

To date, there are no reliable studies on transbasin importations. Detailed studies are necessary in order to determine the

feasibility of any plan. However, because of the ten-year moratorium inserted in the Colorado River Basin Project Act of 1963 on conducting studies of importation to the Colorado River from any river basin outside of the seven Colorado River Basin states, the Secretary of the Interior will not be able to undertake reconnaissance studies of any such water importation plan until after September 1973.

Salinity of the Colorado River would be reduced by importation of a low salinity supply. The extent of reduction would depend on numerous factors, most important of which are the quantity and salinity of the new supply, and the types, magnitudes, and locations of new uses. For example, if 3,500,000 acre-feet a year of water with a salinity of approximately 100 ppm were introduced in the Colorado River Basin after the turn of the century in order to meet the requirements of the Mexican Water Treaty and to maintain Lower Basin uses that would include a full supply to The Metropolitan Water District of Southern California and the Central Arizona Project, salinity in year 2000 at Parker Dam would be 790 ppm instead of the projected 1110 ppm, and at Imperial Dam 990 ppm instead of the projected 1340 ppm. If obtaining a river salinity lower than these values was the purpose of an augmentation project, a substantial quantity of additional water would have to be made available for use below Imperial Dam.

Weather Modification

The Bureau of Reclamation is presently conducting the Colorado River Basin Pilot Project to determine the feasibility of

increasing runoff in the Colorado River Basin by weather modification. Preliminary estimates by the Bureau of Reclamation indicate that an additional 1.87 million acre-feet per year of stream flow might be obtained at a cost of \$1 to \$4 per acre-foot. However, any reliable estimates of the quantity and cost of water to be expected from a weather modification program must await completion of the Pilot Project scheduled for 1975.

Any additional runoff produced from a weather modification program would pick up salts in its travel to Lee Ferry. It is difficult to predict what the salinity effect of a weather modification program might be. However, very rough estimates indicate that if an additional two million acre-feet per year supply would be produced, its effect at Lee Ferry would be that of adding this quantity of water with about 1,000,000 tons of dissolved salts. These additional water and salts would reduce the overall salinity at Lee Ferry by about 70 ppm. For this additional water to benefit California by reducing salinity, a significant portion of it would have to be released at Lee Ferry. If this water were used exclusively to expand Upper Basin uses and the additional dissolved salts were passed on to the Lower Basin, the net result would be even higher salinity values than those projected in Chapter IV.

Desalting of Ocean Water

The Federal Government has been sponsoring intensive research in the water desalting field for several years. To date, the multistage flash distillation process has been found to be

the most economical method of desalting ocean water. Most recent plans for large-scale desalting plants have been predicated upon use of this process, which produces distilled water and leaves a heated, concentrated solution of salts, or brine, that must be disposed of.

In January 1963 the Bureau of Reclamation released a report on the feasibility of desalting ocean water near Camp Pendleton, California, and delivering the desalted water to Lake Mead for use in the Lower Colorado River Basin and for satisfaction of the Mexican Water Treaty obligation. Lake Mead was selected as the terminal point, since a substantial volume of storage would be necessary to meet seasonal peaks of demand, and since the other reservoirs on the lower river reportedly have inadequate unused capacity to supply such demands. While per-acre-foot costs were not included in the report, a unit cost of \$84 per acre-foot could be derived from the data for desalting and transportation to Lake Mead. The costs in the report are based on 1966 price levels and on an estimated level of technological development expected to be achieved by 1990.

Information in the Bureau report has been updated by investigators conducting the Type I, Comprehensive Planning Studies in the Lower Colorado Region. This latter investigation, as yet unpublished, indicates that the cost of desalting ocean water and delivering it to Lake Mead would be between \$125 and \$150 per acre-foot. This would be for a staged operation of desalting plants, using flash-distillation process plants, in coordination

with breeder-type nuclear reactors, in the size range of 700,000 to one million acre-feet per year, conveyed in an aqueduct with a capacity of more than four million acre-feet per year. Capital costs of the plants and aqueduct were estimated to exceed \$5 billion with no allowance for escalation of construction costs, and were based on estimates of future levels of technological development.

A study was made and reported on in 1968 of a nuclear power and desalting plant located on the Gulf of California in Mexico by a joint study team comprised of members from the International Atomic Energy Agency, the United States, and Mexico. The plant would produce about one million acre-feet per year for use in both Mexico and the United States, and would require a capital investment of about \$1 billion for both plant and conveyance facilities. Additional studies would be required in order to determine the feasibility of the proposal.

The effect on the river's salinity of a project that would deliver to Lake Mead the same quantity as that considered for transbasin importation, or 3.5 million acre-feet per year, was investigated for this report. Distilled water would pick up dissolved solids in transit, and it was estimated that the water would contain 50 ppm upon discharge into Lake Mead. This desalted water would reduce the river's projected salinity in year 2000 of 1110 ppm at Parker Dam to 750 ppm, and the projected salinity of 1340 ppm at Imperial Dam to 930 ppm.

Utilization of Geothermal Energy Resources

Recent research by the Institute of Geophysics and Interplanetary Physics at the University of California at Riverside has indicated that there exists a substantial potential in the utilization of the geothermal resources of Imperial Valley as a source of both water and electrical energy. The Institute's preliminary studies suggest that at least one billion acre-feet of geothermal water could be distilled using heat already contained in the water with no additional heat input required. These studies indicate that power produced from steam has a potential in the order of 100,000 megawatts.

The Institute reports that reliable cost estimates can not be forecast until more detailed studies have been made. Advantages stated for this development over a conventional desalting plant are: (1) power produced by the geothermal resources could absorb many of the basic production costs; (2) there would be no cost for heat input (heat input amounts to about 1/4 to 1/3 of average cost of desalting); (3) distillation equipment would be less complex than that required for conventional facilities because, with heat input representing little or no costs, there would be no economic need for many of the stages of the conventional distillation process; and (4) location of the resource is closer to the major Colorado River reservoirs than any other large source of water supply.

A major problem associated with this resource would be the disposal of brine, which should not be released to the Salton Sea.

A considerable amount of work is necessary over a period of several years to determine if the geothermal field can fulfill this promise of providing a major water supply, and to obtain answers to the problems of its use. In addition to the University of California, the Bureau of Reclamation and the Office of Saline Water are investigating this resource in order to determine its potential. The California Department of Water Resources is also interested in the possibilities and has published a report relating thereto (see Bibliography in Appendix).

Desalting of River Water

In addition to the methods discussed in preceding sections, a portion of the river's flow can be desalted and delivered back to the river, thereby directly eliminating a portion of the river's salts. However, unless applied in processing the flow of tributaries containing high concentrations of salts, this method would probably not be practical. Under this method, using flows with concentrated salt loads, it would be possible to process a relatively small volume of water and remove a large amount of salt. Application could be made to some individual point sources of natural salinity as well as to highly concentrated sources of salinity from urban or agricultural discharges to the river's system. Another possibility is desalting water from agricultural return flows within the Colorado River Basin for direct use in the basin service area.

In addition to the multistage flash distillation process previously discussed, the reverse osmosis and electrodialysis

processes may be feasible when considering desalination of the more highly mineralized portions of the river's flow. These processes make use of semipermeable membranes that permit selective transfer of water and salts in solution from one side of the membrane to the other. In the electrodialysis process, the driving force is an electrical charge placed upon the transfer media, whereas in reverse osmosis it is hydraulic pressure. At the present time, costs are in the same order of magnitude for both of these processes. For fairly dilute salt solutions (less than 5,000 ppm), both are less expensive than the multistage flash distillation process. Cost estimates reported by the Office of Saline Water for water produced by plants of a 50,000 acre-foot per year capacity and handling water with 2,500 ppm dissolved solids without preheating are about \$80 per acre-foot.

The Office of Saline Water has been conducting tests on the feasibility of desalting brackish irrigation return flow waters in the Upper Basin, using reverse osmosis pilot plants. The Office reports that at a Grand Junction, Colorado, test location the pilot plants reduced the salinity of return flows from 1,800 ppm to 200 ppm. It was further reported that both electrodialysis and reverse osmosis processes would be equally competitive in treating irrigation return flows.

The membrane processes do not produce completely demineralized water, but remove only portions of the salts in solution during each pass through the process. In addition, some salts are particularly difficult to remove by the membrane process and

tend to remain in solution. These processes also result in a concentrated brine solution that must be disposed of. Therefore, it would be necessary to carefully select site locations for these processes so that the concentrated brine could be disposed of in such a manner that the salts therein would not reenter the Colorado River System.

Salinity Control Projects

There are a number of sources of salinity throughout the basin that could be controlled by individual projects. The Federal Water Quality Administration has identified a number of specific projects and has conducted limited reconnaissance level investigations. The Bureau of Reclamation has completed reconnaissance level studies of one project. The Type I, Comprehensive Framework Studies for the Upper Colorado Region have also identified these projects in its reports (as yet unpublished). Salinity sources include twelve irrigated areas and five natural sources. Five flowing wells that together contributed 100,000 tons of salt annually to the river have already been plugged. The cumulative effect of these projects would accomplish a substantial reduction in the river's salt load. It should be emphasized that these identified projects are not considered to be the only feasible projects, and that other, now unidentified, projects may also prove to be feasible.

The identified projects are briefly described in the following section and are based upon information in the open files of the Federal Water Quality Administration and in the Type I Studies.

Salt sources subject to control are located on Figure 10, "Proposed Salinity Control Projects." Average annual costs, including capital, operation and maintenance costs, are summarized in Table 11.

Irrigated Areas

The twelve irrigated areas vary in size from 100,000 acres in Uncompahgre Valley, Colorado, to several small irrigated areas in Utah and Wyoming. Measures to be used for salinity control would include lining canals, constructing drains, and improving irrigation efficiencies through modification of irrigation practices. These measures would reduce return flows and thereby decrease the quantity of water coming into contact with highly saline ground water and underlying material. Based on studies conducted by the Federal Water Quality Administration, it was estimated that the combination of these control measures would reduce the salt contributed from approximately 600,000 irrigated acres by 1,680,000 tons annually. Average annual costs have been estimated to be \$23,800,000. The unit cost for individual areas varies from a low of \$5/ton/year in Grand Valley, Colorado, to a high of \$12/ton/year in one small area.

In all irrigated areas salinity control works would benefit local irrigators as well as reduce the overall dissolved solids load. These benefits would be in yield increases resulting from lowering of the water table, lower canal operation and maintenance costs, and reduced fertilizer costs.

FIGURE 10

PROPOSED SALINITY CONTROL PROJECTS

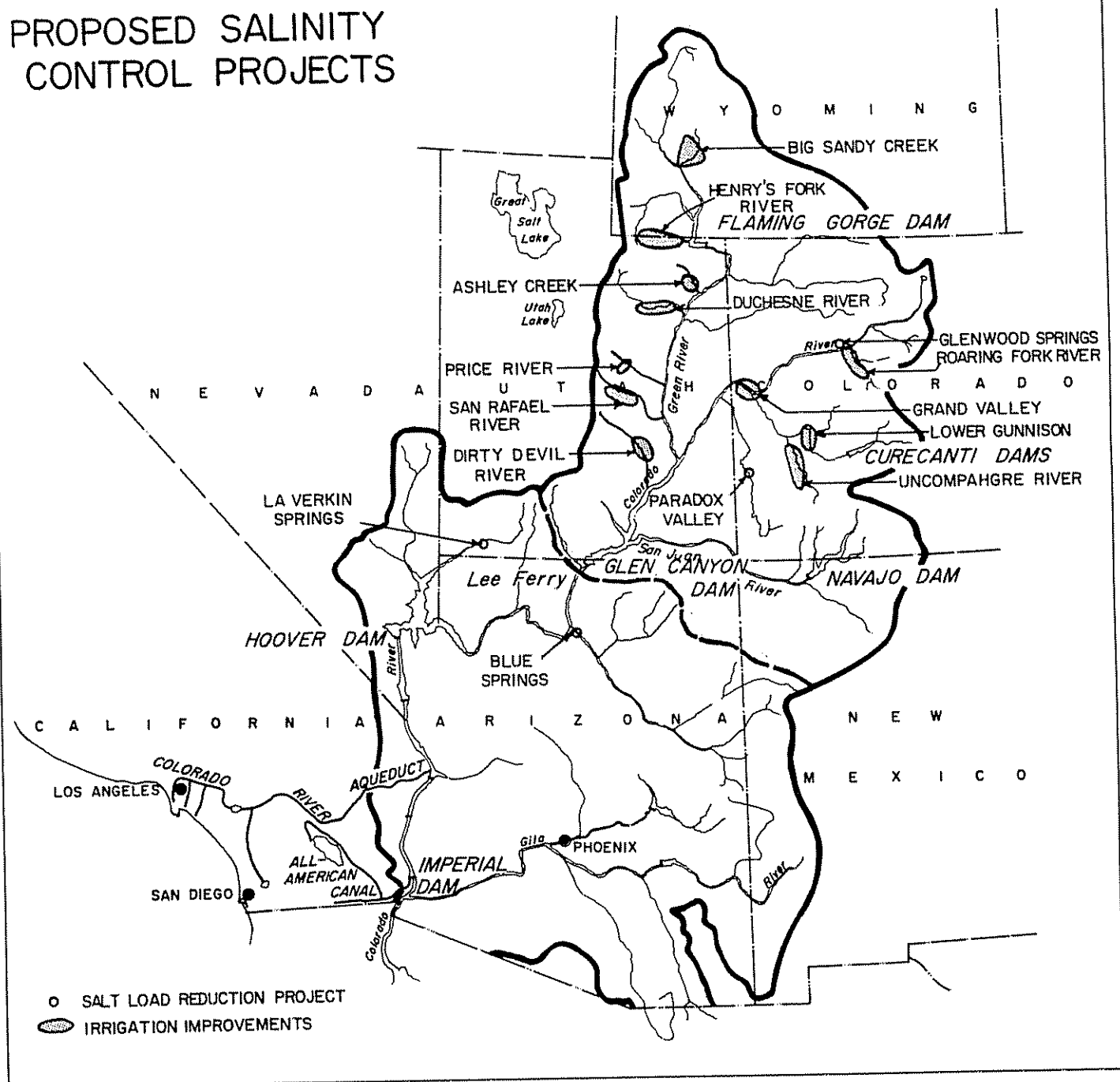


Table 11

ESTIMATED COSTS OF SALINITY CONTROL PROJECTS

Project	Salt Removed (Thousands of Tons/Yr)	Annual Project Costs <u>a/</u> (Thousands of Dollars)	Unit Cost <u>b/</u> (Dollars/ Ton/Yr)
Irrigation Improvements <u>c/</u>			
Grand Valley	310	3,100	5.00
Lower Gunnison River	330	3,600	5.40
Price River	90	1,000	5.70
Uncompahgre River	320	4,000	6.30
Big Sandy Creek	40	490	6.30
Roaring Fork River	50	880	8.50
Upper Colorado River	80	1,400	8.90
Henrys Fork River	40	710	8.90
Dirty Devil River	40	710	8.90
Duchesne River	270	5,700	10.40
San Rafael River	70	1,400	10.50
Ashley Creek	40	800	11.60
Subtotal	1,680	23,790	
Stream Diversion			
Paradox Valley	180	700	3.90
Impoundment and Evaporation			
La Verkin Springs	80	600	7.50
Desalination			
Glenwood and Dotsero Springs	370	5,000	13.50
Blue Springs	500	16,000	32.00
Totals	2,810	46,100	
Weighted Average Unit Cost			12.30

a/ Annual project costs include amortized construction, operation and maintenance costs.

b/ The unit costs only include costs allocated to salinity control.

c/ Annual project costs for irrigation improvements include all costs, including those allocated to the irrigation function. Costs allocated to salinity control projects were estimated to be one-half of total annual project costs.

Paradox Valley

The Dolores River and tributaries flow across and through Paradox Valley, which is underlain with highly soluble saline material. A proposed project includes a dam and regulatory reservoir on one of the tributaries above the valley and an impervious channel for the tributary through the valley. These works would minimize interchange between stream flow and ground water, thereby reducing the salt load of the river by 180,000 tons annually. The average annual cost of this project was estimated to be \$700,000, which gives a unit cost of nearly \$4/ton/year. The Bureau of Reclamation has developed a reconnaissance level plan for the project.

New irrigation in Paradox Valley is included as a minor part of the San Miguel Irrigation Project, authorized by the 1968 Colorado River Basin Project Act. However, irrigation drainage water in the valley might offset some of the salinity control project's effectiveness.

Glenwood and Dotsero Springs

These springs, located in the vicinity of Glenwood Springs, Colorado, are diffuse and would be difficult to isolate; accordingly, it was estimated that only 70 percent of the flow, containing 370,000 tons of salt annually, could be controlled by this project. Captured flows from Dotsero Springs would be conveyed to the vicinity of Glenwood Springs. Here the combined flows of the two spring areas would be processed through a 16 million gallons per day desalting plant. Treated water would be

released back to the river and the brine, which would amount to 5,000 acre-feet per year, would be disposed of by subsurface injection into deep wells a few miles away. The average annual cost was estimated to be \$5,000,000, and the unit cost was estimated to be \$14/ton/year.

Estimated costs are contingent upon utilization of the right-of-way of a proposed highway for the necessary pipeline for conveying Dotsero Springs flows to Glenwood Springs. The route of this new highway has not yet been officially determined; without the right-of-way, construction costs would rise.

Development of an oil shale industry in the area might provide a market for desalted water, thus increasing the feasibility of the project.

La Verkin Springs

As with the preceding springs, La Verkin Springs on the Virgin River are also diffuse springs. It was estimated that about 70 percent of its flow, or 7,000 acre-feet per year, could be captured. The captured flow, estimated to contain 80,000 tons of salt annually, would be conveyed by gravity to an evaporation pond. Annual project costs were estimated to be \$600,000, and the unit cost was estimated to be \$3/ton/year.

Little Colorado River

A project to control Blue Springs, located near the mouth of the Little Colorado River, was developed that would eliminate its annual salt load of 500,000 tons from the river. This project would consist of a low dam constructed downstream from Blue

Springs to intercept the springs' flows and to form a forebay for pumping out of the canyon 3,000 feet above the Little Colorado River, possibly in three separate lifts. This phase of the project could be constructed as a pumped-generating system complex, and it was assumed that a portion of the costs would be allocated to power development. On the ridge overlooking the river, an afterbay would be constructed that would also act as a forebay for a pumping plant that would boost water in a pipeline with a capacity of 200 cubic feet per second southwesterly over the ridge toward Flagstaff. Near Flagstaff, water would pass through two generating stations that would utilize a 2,000 foot drop. At the generating system afterbay, a 200 million gallons per day desalting plant would be constructed. About 140,000 acre-feet of desalted water would be produced thereby and could be sold annually for municipal and industrial use, and about 15,000 acre-feet of brine annually would be ponded to evaporate. The average annual costs would be \$16,000,000, and the unit cost would be \$32/ton/year.

The power portion of the cost is not included. Also, no estimate was made of the cost of this control project without the integrated power features.

Significance of Projects

Completion of all enumerated projects would result in removal of 2.3 million tons annually from the Colorado River and its tributaries upstream from Hoover Dam. Approximately 22,000 acre-feet per year would be removed as brine and evaporated or

injected into deep geological formations. The salts removed would amount to 25 percent of the total annual projected salt load of 11.4 million tons at Hoover Dam in the year 2000.

Cost data on these projects from open file records of the Federal Water Quality Administration were available on an annual cost basis; however, data from Type I, Comprehensive Framework Studies and other sources enable close estimates to be made of the capital costs of the salinity control projects. Projects located in the Upper Colorado River Basin would have a capital cost of approximately \$230 million, and those located in the Lower Colorado River Basin would have a capital cost of about \$150 million.

About 79 percent of the salt would be removed from sources in the Upper Basin, while the balance would be removed from the Lower Basin between Lee Ferry and Hoover Dam. With all projects completed, the full reduction would amount to 360 ppm. Annual costs of salinity control projects divided by the estimated maximum dependable annual virgin water supply of the river, 14 million acre-feet, gives a unit cost of \$3.30 per acre-foot.

Projected salinity at Hoover Dam and other major diversion points is as shown in Table 12 for 1930, 2000, and 2030 for conditions with and without salinity control projects. The projections shown with the projects are based on the assumption that about half of the projects would be completed by 1980 and the balance by 2000.

Table 12

PROJECTED SALINITY
IN THE LOWER COLORADO RIVER WITH AND WITHOUT
PROPOSED SALINITY CONTROL PROJECTS a/

(In Parts per Million)

Station (Along Colorado River)	Average 1963-67	1980		2000		2030	
		Without Projects	With Projects	Without Projects	With Projects	Without Projects	With Projects
Below Hoover Dam	730	830	790	1,050	790	1,090	810
At Parker Dam	740	860	820	1,110	830	1,150	840
At Palo Verde Dam	b/	910	860	1,190	890	1,230	910
At Imperial Dam	850	1,070	990	1,340	1,010	1,390	1,030
At Northerly Interna- tional Boundary	1,300 c/	1,350	1,290	d/	d/	d/	d/

a/ Based on Upper Basin depletions as projected by the Colorado River Board for 1980 and the U.S.B.R. for subsequent years.

b/ Record not available.

c/ Source: International Boundary and Water Commission.

d/ Not estimated.

Financing of Projects

Financing of salinity control projects will be a major problem. Other needs of river basins, such as flood control and river navigation, are satisfied through well-defined programs that rely upon findings of favorable economics, enabling projects to be built which are in the national interest. Possibly a phase of the federal water quality enhancement programs may offer a means of financing projects in the field of salinity control, or new legislation may have to be developed.

A federally sponsored salinity control program on the Colorado River could schedule construction of control projects so that their removal of salt would balance the adverse effects on salinity of water-using projects and the river's salinity could be maintained at approximately current levels. The salinity control projects thus would not be the responsibility of any one entity that may be supporting the construction of a conventional water-using project, but would be a national responsibility and should be sponsored by all states of the Colorado River Basin.

CHAPTER VII
SUMMARY
OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

In brief, our findings, conclusions, and recommendations are as follow:

Findings

1. Currently, the river's salinity increases from an annual average of less than 100 ppm at its headwaters to about 600 ppm at Lee Ferry, the Upper-Lower Basin division point. At Imperial Dam the salinity averages over 800 ppm with seasonal values in excess of 1100 ppm.
2. The river's present annual salt load at Lee Ferry is approximately 8.5 million tons. The combination of salts contributed by man to the river and depletions caused by man's activities account for 50 percent of the salinity at Lee Ferry.
3. The Grand Canyon station has the longest continuous salinity record on the river. Within the range of annual fluctuations the salinity was fairly constant from 1926-51. Since then, there has been a general rise in salinity.
4. Pickup of salts from irrigated areas has been the major salinity source resulting from man's activities in the Colorado River Basin. Studies indicate an annual pickup rate ranging from 0.1 to 3.5 tons per irrigated acre in the Upper Basin. In the Lower Basin the range is 0.5 to 2.3 tons per irrigated acre.
5. Salinity at Imperial Dam has been increasing at a more rapid rate in recent years than has salinity at upstream stations.

6. There are significant variations in salinity during the year, with the highest seasonal level of salinity at Imperial Dam occurring during the critical winter months when salt-sensitive seeds for vegetable crops are germinating in the desert valleys.
7. The major cause of salinity variations during the year at Imperial Dam is the varying ratio between return flows entering the river below Parker Dam and the total river flow.
8. Salinity of water delivered to Mexico near the International Boundary peaked in the early 1960's, but in recent years has decreased as a result of operating procedures undertaken by the United States and Mexico. Salinity, however, remains a major problem between the two countries.
9. Salinity of the water supply damages agricultural areas in one or more of the following ways: reduced crop yields, damage to salt-sensitive plants, drainage problems, increased costs, and increased demands on a scarce water supply.
10. Salinity of the water supply has an adverse effect on domestic users in one or more of the following ways: taste, gardening problems, water softening costs, and corrosion problems in pipelines and water-using equipment.
11. Salinity of the water supply damages industrial users in one or more of the following ways: higher treatment and conditioning costs for various uses, corrosion of pipelines and facilities, and increased operation and maintenance costs.

12. Existing water development projects financed by the Federal Government contribute significantly to salinity of the river, and future increases will result, in part, from new projects financed by the Federal Government. Also, 67 percent of the lands in the Upper Basin are owned by the Federal Government.

Conclusions

1. If salinity controls are not adopted, additional use from existing projects and new uses from projects under construction, authorized or in the planning stage, will cause Colorado River water to continue to increase in salinity.
2. If water development projects are constructed as projected in this report, average virgin flow at Lee Ferry is 14 million acre feet per year and no salinity control measures are taken, salinity at Parker Dam will increase from an average of 740 ppm for the 1963-67 period to a projected value of approximately 860 ppm in year 1980. At Imperial Dam the values are 850 ppm and 1070 ppm. Peak seasonal values will be higher.
3. If the average annual water supply is one million acre-feet per year more than projected, salinity will be about eight percent less than the above figures. If the water supply is one million acre-feet per year less than projected, salinity will be about nine percent greater than the above figures.
4. Without salinity control projects, the projected year 2000

salinity is 1110 ppm for Parker Dam and 1340 ppm for Imperial Dam.

5. Approximately 74 percent of the salinity increase at Imperial Dam from the 1963-67 average to year 2000 is due to projected Upper Basin developments and 26 percent is due to projected Lower Basin developments.
6. Without salinity control measures, all of the planned Colorado River Basin projects, except for the Central Arizona Project, will contribute to increased salinity at Parker and Imperial Dams.
7. The problem is severe, and salinity control measures should be started soon in order to prevent the above projections from becoming a reality.
8. The Federal Government bears a strong responsibility to seek cooperative solutions to salinity problems with the states and concerned agencies because of construction and operation of federally financed projects and ownership of lands.
9. The Secretary of the Interior has announced a policy through his "Guidelines for Establishing Water Quality Standards for Interstate Waters" and his required anti-degradation statements that further degradation of water quality is not acceptable.
10. Problems of quantity and quality are interrelated and should be approached through comprehensive planning efforts.
11. Augmentation of the river with a low salinity water supply would ameliorate the salinity problem; however, at this

time there is no project in the planning stage that would accomplish this purpose.

12. Damages to California interests have been estimated to be in the order of \$8 - \$10 million per year for each 100 ppm increase in salinity at Imperial Dam. This gives an annual rate in excess of \$40 million by the year 2000 in the absence of salinity control projects. Damages to the other states and Mexico would also be significant.
13. A number of salinity control projects have been investigated by federal agencies on a reconnaissance level basis. In total, it is estimated that the identified projects would remove 2.8 million tons of salt per year, or about 25 percent of the 11.4 million tons of salt estimated to reach Hoover Dam at the year 2000, and annually thereafter.
14. Approximately 79 percent of the above salt would be removed by projects constructed in the Upper Basin and 21 percent would be removed by Lower Basin projects constructed between Lee Ferry and Hoover Dam.
15. If constructed in a timely manner, these salinity control projects would reduce the projected salinity at Parker and Imperial Dams by about 25 percent.
16. Salinity control projects are estimated to cost \$380 million and unit cost of salt removal is estimated to be generally within the range of from \$4 to \$12 per ton of salt per year. Dividing total annual costs of the above salinity projects

by the estimated maximum dependable annual virgin flow at Lee Ferry results in a unit annual cost in the order of \$3 per acre-foot of mainstream water.

Recommendations

1. The key policy objective should be to maintain salinity of the Lower Colorado River at or near present levels.
2. To accomplish the above objective, construction of salinity control projects should be scheduled for completion coincident with the completion of water projects that would increase salinity in the Colorado River Basin in order to offset such increases and maintain salinity in the Lower Colorado River Basin near present levels.
3. Meetings should be held with the other Colorado River Basin states and the Federal Government for the purpose of establishing an action program to accomplish the above recommendation through controlling Colorado River salinity within the framework of basinwide planning.
 - a. The reconnaissance level salinity control measures which have been prepared to date by federal agencies should be reviewed and feasibility studies immediately commenced on all projects that are sufficiently well defined and that show promise at the reconnaissance level.
 - b. Investigations on a reconnaissance level should be continued to identify other salinity control measures.

- c. Financing and legislation should be developed for a Colorado River salinity control program that would provide for federal construction of salinity control projects.
- 4. The basin states should work to obtain Congressional authorization and funding for the Colorado River salinity control action program.
- 5. Meetings should be held with the other basin states and the Federal Government for the purpose of establishing numerical values for Colorado River salinity criteria as part of each state's water quality standards under the Federal Water Quality Act.
 - a. Numerical values reflecting the principle that salinity levels should remain near present levels by balancing salinity control projects and water development projects should be incorporated in criteria for each of the Colorado River Basin state's water quality standards.
 - b. Each state's water quality standards should provide for implementation of the numerical salinity criteria through construction of salinity control projects or other feasible measures.
- 6. The basin states should continue to work for augmentation of the Colorado River as an additional solution to the salinity problem.

A P P E N D I X

TABLE A

WATER AND DISSOLVED MINERAL CONTRIBUTIONS FROM NATURAL ^{a/}
ORIGIN POINT SOURCES COLORADO RIVER BASIN

(Sheet 1 of 2)

<u>Green River Subbasin</u>	<u>Flow Acre-Feet/Year</u>	<u>Salt Load Tons/Year</u>
Warm Kendall Spring	4,000	6,570
Cold Kendall Spring	1,014	2,920
Coal Mine Drainage near Oak Creek, Colorado	482	2,190
Steamboat Springs Mineral Springs	1,014	3,760
Jones Hole Creek-Whirlpool Canyon		7,665
Split Mountain Warm Springs	14,500	18,615
Test Hole near Jensen, Utah		365
Stinking Spring	50	365
Indian Creek Springs	470	1,095
Meeker Oil Test Hole	2,244	58,400
Piceance Creek Well	16	6,205
Crystal Geyser	204	19,345
Subtotal	23,994	132,495
<u>Upper Main Stem</u>		
Hot Sulphur Springs	0	0
Dotsero Spring	12,308	160,600
Glenwood Springs Area	13,032	335,800
Ouray Hot Springs	725	1,460
Ridgeway Hot Springs	724	2,555
Paradise Hot Spring	30	730
Paradox Valley		251,120 ^{b/}
Subtotal	26,869	752,265

^{a/} Federal Water Quality Administration open files Denver, Colorado.

^{b/} Measured increase in salt load of the San Miguel River while flowing through the Paradox Valley, Colorado. Average annual flow at Haturita, Colorado, for 39-year period 1928-67 is 249,000 acre-feet.

(Sheet 2 of 2)

<u>San Juan Subbasin</u>	<u>Flow Acre-Feet/Year</u>	<u>Salt Load Tons/Year</u>
Pagosa Hot Springs	1,665	7,300
Pinkerton Hot Spring	362	1,825
	<hr/>	<hr/>
Subtotal	2,027	9,125
	<hr/>	<hr/>
Total Upper Basin	52,390	393,685
 <u>Lower Colorado River Basin</u>		
Blue Springs	159,000	547,500
Miscellaneous small springs above Grand Canyon	10,200	3,650
Vulcan or Lava Falls Spring		3,650
Miscellaneous springs above Virgin River		7,665
Havasui Spring	47,000	23,725
La Verkin Spring	7,200	104,390
Littlefield Salt Springs	7,200	29,565
Roger Spring	1,500	6,250
	<hr/>	<hr/>
Total Lower Basin	232,100	726,350
Grand Total - Colorado River Basin	264,990	1,620,235

Table B

PROJECTED UPPER BASIN DEPLETIONS AT LEE FERRY

	(Thousands of Acre-Feet per Year)				U. S. Bureau			
	Colorado River Board of California a/		of Reclamation b/		River Commission c/			
	1980	2000	2030	2040	1980	2000	2030	2040
Average 1963-67 Estimated Depletion d/	2,740	2,740	2,740	2,740	2,875	2,875	2,875	2,875
Projects Under Construction or Authorized								
Irrigation Projects								
Animas-La Plata (Colorado, New Mexico)		69	146	146	27	146	146	146
Bostwick Park (Colorado)	4	4	4	4	4	4	4	4
Central Utah Project (Utah)	55	55	55	55	55	55	55	55
Dallas Creek (Colorado)	20	20	37	37	37	37	37	37
Dolores (Colorado)	60	60	87	87	74	74	74	74
Emery County (Utah)	17	17	17	17	17	17	17	17
Fruitland Mesa (Colorado)	28	28	28	28	28	28	28	28
Hammond (New Mexico)	10	10	10	10	4	4	4	4
Hogback Expansion (New Mexico)	20	20	20	20	10	10	10	10
Lyman (Wyoming)	10	10	10	10	10	10	10	10
Navajo Indian Irrigation (New Mexico)	84	135	200	250	84	254	254	254
Navajo Reservoir Evaporation (New Mexico)	30	30	30	30	10	10	10	10
San Miguel (Colorado)	26	40	85	85	38	85	85	85
Savery-Pot Hook (Colorado, Wyoming)	64	38	38	38	38	38	38	38
Seedskaadee (Wyoming)	6	90	165	165	64	122	122	135
Silt (Colorado)		6	6	6	6	6	6	6
West Divide (Colorado)		30	76	76		76	76	76
Subtotal	434	662	1,014	1,064	468	976	976	989
Industrial Projects								
Arizona Allotment (Arizona)	35	35	35	35	40	40	40	40
Hayden Steam Plant (Colorado)	12	12	16	16	8	12	12	12
Navajo Reservoir Developments (New Mexico)	100	100	100	100	60	60	60	60
Ruedi Reservoir Developments (Colorado)	30	30	40	40	40	40	40	40
Utah Construction Company (New Mexico)	40	40	40	40	60	107	107	111
Westvaco and Other Developments (Wyoming)	60	60	107	111	60	107	107	111
Subtotal	277	277	338	342	208	259	259	263

Table B
(cont'd)

PROJECTED UPPER BASIN DEPLETIONS AT LEE FERRY

	(Thousands of Acre-Feet per Year)					Upper Colorado		
	Colorado River Board of California a/		U. S. Bureau of Reclamation b/		River Commission c/	River Commission c/		2020
	1980	1980	2000	2030		1980	2000	
Transmountain Diversions								
Central Utah Project (Utah)	100	100	166	166		100	166	166
Cheyenne and Laramie (Wyoming)	18	18	31	31		15	25	30
Denver, Englewood, Colorado Springs, and Pueblo Diversions (Colorado)	104	104	209	234		103	259	259
Fryingpan-Arkansas (Colorado)	70	70	70	70		70	70	70
Green Mountain M&I (Colorado)	12	12	12	12				
Homestake (Colorado)	45	45	74	74			41	41
Independence Pass Expansion (Colorado)	14	14	14	14			14	14
San Juan-Chama (New Mexico)	110	110	110	110		110	110	110
Subtotal	473	473	686	711		398	685	690
Total Under Construction or Authorized	1,184	1,412	2,038	2,017		1,074	1,920	1,942
Current Proposals for Projects								
Irrigation Projects								
Basalt (Colorado)							26	26
Battlement Mesa (Colorado)							12	12
Bluestone (Colorado)							24	60
Central Utah, Emery-Ferron Area and Southeast Area (Utah)						64	283	510
Eagle Divide (Colorado)							19	19
Eden Improvement (Wyoming)						10	10	10
Grand Mesa (Colorado)							23	23
Lower Yampa (Colorado)							102	102
Middle Park (Colorado)							29	29
Private Irrigation Projects (Wyoming)							27	27
Sublette (Wyoming)						13	20	100
Upper Gunnison (Colorado)						45	100	100
Upper San Juan (Colorado)							10	10
Upper Yampa (Colorado)							6	6
Yellow Jacket (Colorado)							47	63
Subtotal						132	663	1,044

Table B
(cont'd)

PROJECTED UPPER BASIN DEPLEITIONS AT LEE FERRY

	(Thousands of Acre-Feet per Year)									
	Colorado River Board of California a/			U. S. Bureau of Reclamation b/			Upper Colorado River Commission c/			
	1980	2000	2030	1980	2000	2030	1980	2000	2020	2020
Industrial Projects e/										
Future Additional Needs (New Mexico)							42	98		187
Morgan Lake Power (New Mexico)							24	24		24
Oil Shale Industry (Colorado, Utah, Wyoming)								100		134
Resources Incorporated (Utah)	31	102	102	31	102	102	3	94		103
Subtotal	31	102	102	31	102	102	69	316		448
Transmountain Diversions										
Four County (Colorado)	20		40	20	40	40		40		40
Potential Diversions (Colorado, Wyoming)							50	125		851
San Juan-Chama, 2nd Stage (New Mexico)								125		125
Subtotal	20		40	20	40	40	50	290		1,016
Total Current Proposals for Projects	51		142	51	142	142	251	1,269		2,508
Total All Irrigation Projects	434		1,014	662	1,014	1,064	600	1,639		2,033
Total All Industrial Projects e/	308		440	308	440	444	277	575		711
Total All Transmountain Diversions	493		726	493	726	751	448	975		1,706
Projects Not Identified	84		223	84	223	332				
Total All Projects	4,054		5,143	4,282	5,143	5,331	4,200	6,064		7,325
Estimated Salvage	- 164		- 191	- 164	- 191	- 191				
Evaporation From Storage Units	660		660	660	660	660	660	660		660
Total Depletions at Lee Ferry	4,550		5,612	4,778	5,612	5,800	4,860	6,724		7,985
Total Future New Irrigated Acreage (Acres)	141		340	213	340	362	236	638		780

(a) Colorado River Board adjustments to USBR estimates (see footnote b) to reflect results of recent investigations and affect of delays and reductions in appropriation of federal funds for certain projects.

(b) Source: U. S. Bureau of Reclamation, Mead-Powell Operating Criteria Basic Data, dated July 15, 1969.

(c) Source: Upper Colorado River Commission, Mead-Powell Operating Criteria Basic Data, dated December 2, 1969.

(d) Does not include average of 203,000 acre-feet mainstream reservoir evaporation for the 1963-1967 period.

(e) Includes attendant municipal use.

Salt Load Contribution by Upper Basin Projects

In a study conducted by the U. S. Geological Survey for the period 1914 to 1957, weighted annual average of salt load in the Colorado River, as a result of irrigation in the Upper Colorado River Basin, was estimated at 2.4 tons per acre. More recent studies made by the Bureau of Reclamation indicate that salt yield per acre on newer projects may be somewhat less than 2.4 tons per acre, and the Bureau of Reclamation in its water quality reports of the Colorado River Basin has used an assumed value of 2.0 tons per acre annually, in addition to an alternative assumption of no salt pickup. The Federal Water Quality Administration in Appendix A of its forthcoming report, "The Mineral Quality Problem in the Colorado River Basin"(unpublished), determined that in 1963 the average of salts added from irrigation was about 1.7 tons per acre annually. After analyzing available information, it was decided for this report to base projections of future salinity on salt additions of 2.0 tons per acre annually from irrigation of new lands in the Upper Colorado River Basin.

Depletions for Irrigated Agriculture in the Upper Basin

Prior studies by the U. S. Bureau of Reclamation have indicated that irrigation developments in the Upper Basin in the past have depleted water at the rate of approximately 1.3 acre-feet per acre annually. In many cases, the irrigated areas did not have a full supply for irrigation, particularly during the latter part of the irrigation season. Recent irrigation projects have provided a full supply for existing irrigation areas, and all new lands irrigated through future projects are expected to have a full supply for irrigation throughout the season.

Estimates from the Type I Framework Studies indicate that present depletions by irrigated agriculture amount to slightly less than 1.5 acre-feet per acre, and that by year 2020 irrigation depletions will be slightly greater than 1.5 acre-feet per acre.

Based on the above estimates, it was concluded that a use-rate of 1.5 acre-feet per acre per year for all irrigated lands in the Upper Basin would more accurately reflect expected future water use.

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